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# The Effects of a Fire on Radio Wave Transmissions

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13. ABSTRACT (Maximum 200 words)  The Naval Research Laboratory Code 6180 investigated the losses of an electromagnetic signal when transmitted through a hydrocarbon pool fire. This report documents an experiment which consisted of eight full scale fire tests at NRL's Chesapeake Bay Division (Chesapeake Bay Fire Test Facility) in Calvert County, Maryland on both December 23, 1996 and again on January 8, 1997. The background research, experimental approach, and presentation of results for this experiment are contained herein.				
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# THE EFFECTS OF A FIRE ON RADIO WAVE TRANSMISSIONS

## I. INTRODUCTION

The US Navy has observed a loss in communication capability in areas surrounding a turbulent hydrocarbon fire. It was speculated that the ionization within the fire played a role in this phenomena. Significant work has been completed in documenting the production, formation, and concentration of ions in the combustion process. A non-exhaustive literature search has revealed work involving the characterization of ions and electrons in pre-mixed (non-turbulent) "burner" flames. These works showed that laminar flames could be characterized as a *plasma*, and thus used plasma equations to determine the concentration of ions and electrons.

The goal of this experiment was to investigate the mode in which radio frequency signals were attenuated (or completely lost) when transmitted through a turbulent hydrocarbon (heptane) pool fire.

This experiment consisted of a series of tests that transmitted radio signals through a heptane pool fire. Each test transmitted signals at frequencies from 50 MHz to 1000 MHz at 10 MHz intervals; a range consistent with typical communication systems. The signals were recorded and compared against a similar transmission without the obstruction of a fire. The losses (or gains) were noted and are presented here.

From plasma theory, it is well documented that when transmitting at the *plasma frequency*, the signal is reflected at the plasma boundary. An increase in frequency yields a deeper penetration into the plasma. Since the plasma frequency of a turbulent heptane pool fire was not known, a range of frequencies was transmitted. The detection of a reflection would provide information on the plasma frequency which in turn would describe an important mode of signal loss.

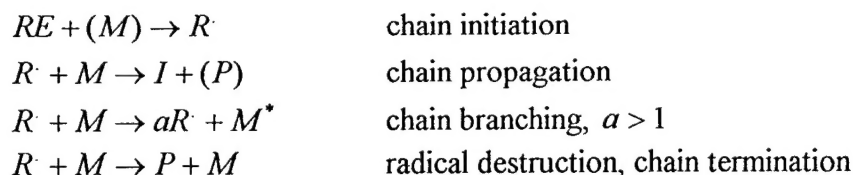
Signal reflection did not occur in any of the tests. This may have been caused by a.) the transmitted frequencies were above the plasma frequency and/or b.) the plasma boundary (fire boundary) was too dynamic.

An important result was noted, however. The transmitted signal was found to rotate when passing through the fire. This can be described as a plasma phenomenon known as *Faraday Rotation*. This fact is important because it describes one mode in which signal loss occurs. If a vertically polarized signal (from a hand held radio with a vertical antenna) was transmitted through a fire, the fire would rotate the signal so that only a portion of the energy would be acquired at the receive end. In addition to the rotation, the transmitted signal was shown to be amplified at certain (random) frequencies. It is suspected that this amplification is caused from signal phase shifting and/or energy scattering within the fire (multiple waves arriving at the receiver at essentially the same time).

## II. BACKGROUND RESEARCH

### II.A. IONIZATION WITHIN A FIRE:

Call and Schwartz<sup>[1]</sup> provide a summarization of the production of ions in fires. In general terms, there are four types of chain reactions that occur in the combustion process:



where RE is a reactant, M is a molecule,  $R\cdot$  is a radical, I is an intermediate product, and P is a final reaction product. The parentheses around M and P indicate that they may be involved in the reaction but not necessarily, and the asterisk \* indicates an excited internal energy state. The chain branching reaction is most important in the work being proposed here, in that it produces multiple ( $a > 1$ ) free radicals that may react again.

Lawton and Weinberg<sup>[2]</sup> provide a more detailed discussion on the formation of ions. They cite the following four (4) processes for ion production:

1. Ionization by collision:  
 $A + B \rightarrow A^+ + B + e^-$   
 $A + e^- \rightarrow A^+ + e^- + e^-$
2. Ionization by electron transfer:  
 $A + B \rightarrow A^+ + B^-$
3. Ionization by transfer of excitation energy:  
 $A + B^* \rightarrow A^+ + B + e^-$
4. Chemi-ionization:  
 $A + B \rightarrow C^+ + D + e^-$   
 $A + B \rightarrow C^+ + D^-$

From the above equations, it is obvious that charged particles exist within a fire. By definition, a plasma is "*a collection of charged particles resembling a gas but differing from it as it conducts electricity and is affected by a magnetic field*"<sup>[3]</sup>. The work completed by Call and Schwartz shows that a fire is affected by a magnetic/electric field, and can therefore be considered a plasma. Lawton and Weinberg discuss the propagation of electromagnetic waves through plasmas. The equations used to characterize a plasma with respect to its electromagnetic parameters provide additional information on the concentration of electrons and/or ions within the fire.

## **II.B. OBJECTIVE OF WORK:**

The US Navy has observed a loss in communication capability in areas surrounding a turbulent hydrocarbon fire. It was speculated that the ionization within the fire played a role in this phenomena.

The goal of this experiment was to investigate the mode in which radio frequency signals were attenuated (or completely lost) when transmitted through a turbulent hydrocarbon (heptane) pool fire.

This experiment consisted of a series of tests that transmitted radio signals through a heptane pool fire. Each test transmitted signals at frequencies from 50 MHz to 1000 MHz at 10 MHz intervals; a range consistent with typical communication systems. The signals were recorded and compared against a similar transmission without the obstruction of a fire. The losses (or gains) were noted and are presented here.

A explanation of the measured losses will be provided, and recommendations for further study will be presented.

### III. EXPERIMENTAL APPROACH

#### III.A. BRIEF DESCRIPTION OF TEST PROCEDURES:

The objective of this experiment was to obtain information on the changes of a waveform when transmitted through a turbulent hydrocarbon pool fire. The waveform consisted of a sinusoid of varying frequencies; 50 to 1000 megahertz in 10 megahertz intervals. In order to control the test and acquire the data, a software program, appendix A, had to be developed. This program was run on a Pentium computer with a GPIB (General Purpose Interface Bus) card installed. The GPIB card allowed the software to communicate with a Hewlett Packard (HP) Signal Generator and to a Tektronix Digitizing Oscilloscope. The HP Signal Generator was then connected to a radio frequency amplifier which was connected to a transmitting Biconical Antenna. The antenna allowed transmission of the wave through the fire. The signal was then received by two receive Biconical Antennas which were connected to the digitizing oscilloscope. The oscilloscope recorded the wave and transferred the data back to the Pentium computer to be stored on disk. Since the goal was to obtain the effects from the fire, each transmission series was run twice: once without the fire (from hereon termed "baseline"), and once with the fire. The waveforms of the baseline transmission were then compared to those transmitted through the fire and any losses or changes were noted.

The raw data received consisted of 500 voltage points per waveform. Each test consisted of 95 different frequency points, with 500 voltage points (one waveform) per frequency, and eight different tests being run twice (baseline and with the fire) the number of data points acquired was:

$$(95 \text{ frequencies}) \times (500 \text{ data points/frequency}) \times (8 \text{ tests}) \times (2) = 760,000 \text{ data points}$$

When these voltage points are plotted against time, multiple sinusoid waveforms are displayed. A second computer program, appendix B, had to be developed to assist in the analysis of all the acquired voltage points. This software converted the 760,000 voltage points into individual sinusoidal waveforms. Very little information could be obtained from looking at the individual waveforms (except to see if the data acquisition was successful). Therefore, the program compared each waveform obtained by transmitting through the fire, with its corresponding baseline waveform (of the same frequency). The easiest way to do this was to perform a Fourier Transform of the time domain sinusoidal waveforms to obtain the corresponding power spectrum (frequency domain). For each frequency, a maximum power was displayed. The maximum power of each baseline waveform was compared with its corresponding waveform transmitted through the fire and the results were plotted.

The following sections provide a more detailed description of the experimental procedures including the data acquisition/control software design, the physical test parameters, and the data analysis software design.

### III.B. TEST SETUP AND TEST SITE:

#### III.B.1. TEST SETUP:

The test setup is shown in Figure 1 below (see Appendix C for specifications of equipment):

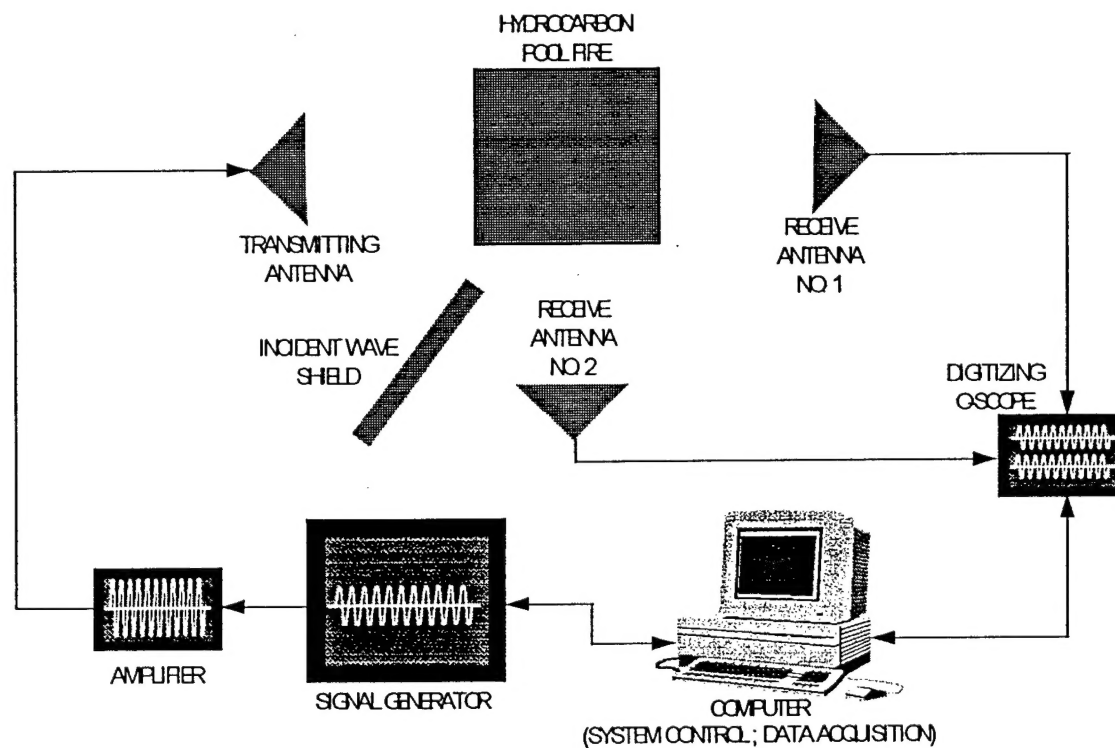


FIGURE 1 : TEST SETUP

Computer: IBM Compatible, Pentium processor, 120 MHz, 8 megabytes RAM

Signal Generator: Hewlett Packard HP8648C Signal Generator

Digitizing Oscilloscope: Tektronix TDS784A Digitizing Oscilloscope

Amplifier: ENI/607L Power Amplifier

Antennas: Log Periodic/Biconical Antenna Model LPB-2520 (25-2000 MHz)

As previously described, the test was controlled by software running on a Pentium computer. The computer communicated with the HP Signal Generator in order to develop a sinusoidal waveform. This waveform was sent to the transmit antenna via the RF amplifier. The signal was transmitted through a 121.92 cm X 121.92 cm (four foot square) n-heptane pool fire. The signal was then acquired by the two receive antennas.

The locations of the receive antennas were varied in order to investigate the radio wave from different perspectives (see Section III.D.3 for more information on the various antenna configurations). The incident wave shield (used only in Test 6, 7, & 8) was used to block the transmitted signal so that only a reflected signal from the fire would be acquired. Ideally,

multiple antennas would have been placed around the fire in order to determine if the fire reflected the signal in all directions. However, the budget for this experiment only allowed for the three antennas shown above.

Once the signal was obtained at the receive antennas, it was recorded by the digitizing oscilloscope. When the complete waveform was recorded, the oscilloscope sent the information back to the computer to be stored on disk. The frequency was then increased by 10 MHz and the process was repeated until the frequency reached 1000 MHz.

### **III.B.2 TEST SITE:**

Naval Research Laboratory's Chesapeake Bay Detachment: This experiment took place at the Naval Research Laboratory's Chesapeake Bay Detachment (NRL CBD) in Calvert County, Maryland. The Chesapeake Bay Fire Test Facility is concerned with all aspects of shipboard fire safety, particularly as related to flight decks, submarines and interior ship conflagrations. The emphasis of this facility is on providing for intermediate scale, credible evaluations of firefighting agents, systems and training concepts under more realistic shipboard conditions. In many cases, the facility provides a vital link between laboratory testing and full scale proof of concept on the ex-USS SHADWELL (a decommissioned Navy ship now used for various testing, located in Mobile, AL., ref. (4)). The Facilities Manager at CBD is Mr. Roger A. Brown (410-257-4134).

Below is an aerial photograph of the CBD facility (fig. 2). Note the large cement platform in the middle of the picture. This platform is where the experimental fires for this experiment were conducted:

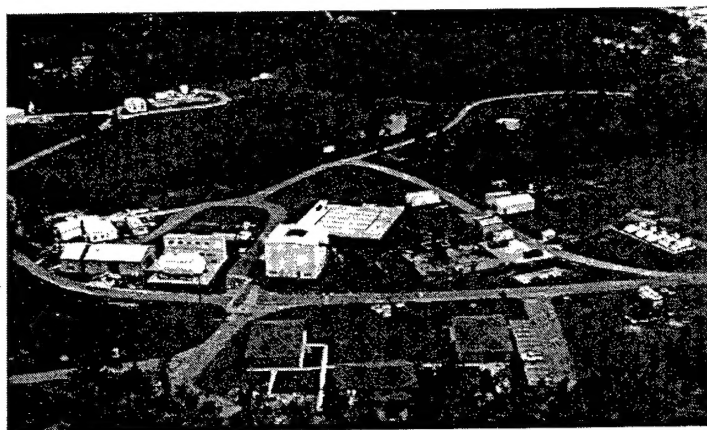


Figure 2. NRL CHESAPEAKE BAY FIRE TEST FACILITY

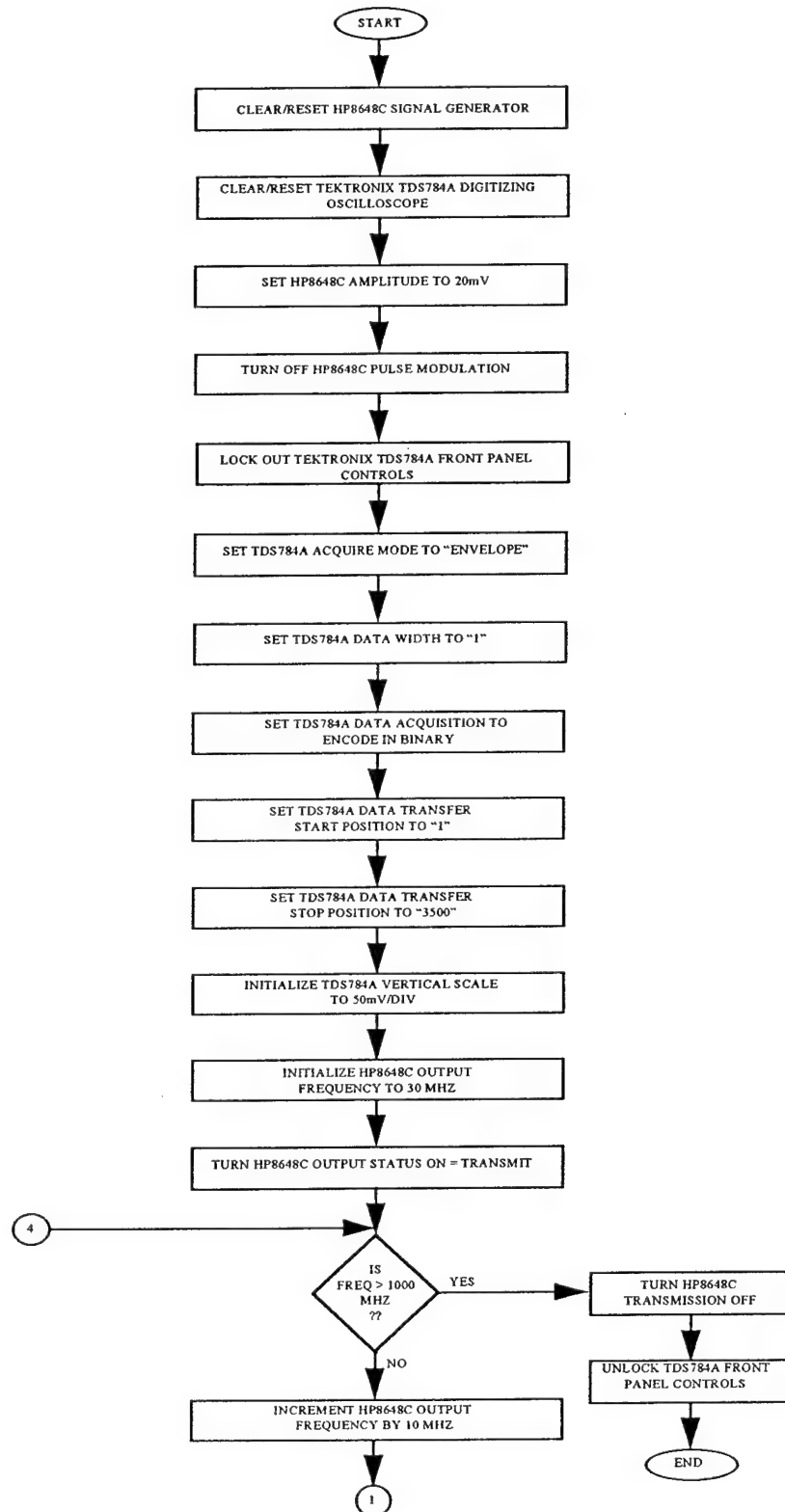
### **III.C. DATA ACQUISITION/CONTROL SOFTWARE DESIGN:**

The software compiler used to develop the data acquisition and control software for this experiment was National Instruments "LABVIEW". This software package allows a user to create a software program by using graphics instead of the common command line programming. This programming language is termed "G". At its basic structure, it is similar to the "C" programming language. The LABVIEW compiler contains many library components to assist in programming; for-next loops, while loops, multiplication subroutines, max/min subroutines and string functions. The user is then left to "wire" up each of these subroutines to create the software flow desired. Since LABVIEW is graphical, it is easy to "watch" the flow of the software, which reduces debugging time. LABVIEW was chosen for this experiment because of its compatibility and ease of use with GPIB hardware. In addition, LABVIEW contains a very sophisticated data analysis library that was used later in this experiment.

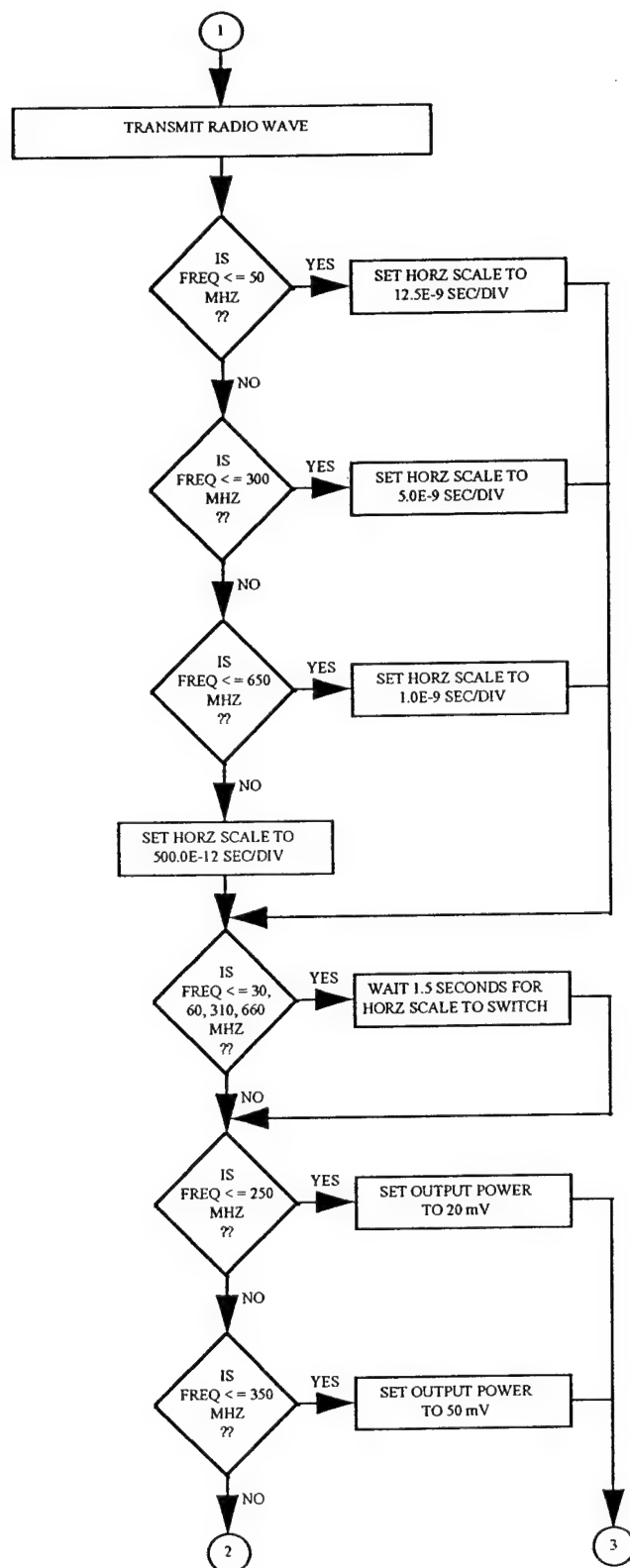
The flow chart shown in Figure 3 depicts the data acquisition/control software used in this experiment (see Appendix A for actual software program). The software program first initializes the GPIB protocol and assigns each piece of experimental equipment an address. This address is unique to each instrument and will allow the computer to "talk" to each piece of equipment separately or as a group. The initialization also consists of locking out the front controls of the oscilloscope, setting the data acquisition mode to envelope, and recording the data in binary. The enveloping data acquisition mode acquires a set amount of waveforms (in this experiment 3 to 6) and records a maximum and a minimum data point for each time interval. Binary encoding, (versus ASCII) is cryptic but allows for fast data acquisition and data storage.

The next section of the program is a loop that tests to see if the frequency is greater than 1000 MHz. If it is, the experiment is over and the test stops. If the frequency is less than 1000 MHz, the radio wave transmission takes place as well as the data acquisition. In order to view and acquire the radio waves appropriately, the oscilloscope horizontal scale is required to be of the same range as the transmitting frequency. Therefore the oscilloscope horizontal scale is set in accordance with the transmission frequency. The output power of the transmitting signal is then boosted with an increase in frequency. This was required due to the impedance and the losses inherent in the test set-up and the frequency response of the antennas, signal generator, amplifier, RF cables and connections. When the experiment was run with no amplification in the signal, the higher frequencies were not observable (even without the fire). The signals were therefore boosted until the signal to noise ratio was at least ten times.

The vertical scale on the oscilloscope was set to 50 mV/div for all tests. The vertical scale was kept constant in order to compare the received power for different frequencies. The final stage of the program acquired the waveform data points and transferred them back to the computer to be saved on disk. The frequency was increased by 10 MHz and the process began again.



**Figure 3A. Data Acquisition/Experiment Control Software**



**Figure 3B. Data Acquisition/Experiment Control Software**

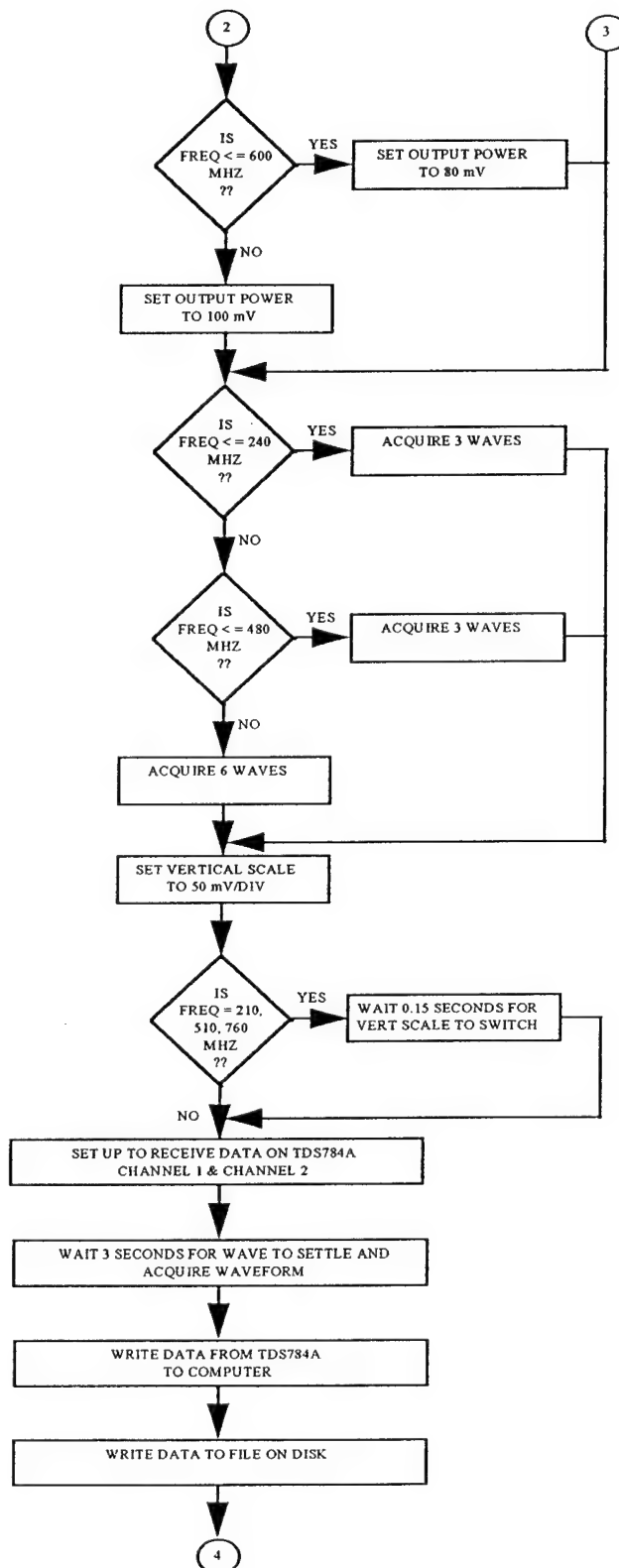


Figure 3C. Data Acquisition/Experiment Control Software

### **III.D. PHYSICAL TEST PARAMETERS:**

This section describes the physical test parameters involved in this experiment. The following topics will be expanded upon:

- (1.) Fuel Parameters (density, flash point and weight)
- (2.) Fire Size (flame height, pool size and amount of fuel)
- (3.) Antenna Placement (for each test)

#### **III.D.1. FUEL PARAMETERS:**

The fuel that was used for this experiment was heptane ( $C_7H_{16}$ ). Heptane was chosen because:

- it is a hydrocarbon - this experiment was developed to assist the Navy in determining the cause of radio transmission problems during a hydrocarbon (such as; jet fuel, gasoline or diesel fuel marine) pool fire
- it burns cleaner (more efficiently) than kerosene, gasoline, or diesel thus allowing the study of the ionization properties of fire by lessening some of the soot particles that may interfere with the transmission of radio waves,
- it is readily available
- it is relatively inexpensive

Table 1 lists the parameters of n-Heptane:

1	Formula	$C_7H_{16}$
2	Weight	100 kg/mol
3	Normal Boiling Point ( $T_b^\circ$ )	371 K
4	Enthalpy of Vaporization ( $h_{fg}^\circ$ )	365 kJ/kg
5	Enthalpy of Combustion ( $h_c$ )	45.0 MJ/kg
6	Flash Point Temperature in Air @ 1 ATM ( $T_f^\circ$ )	269 K (closed)
7	Lean Flammability Limit by Volume	0.012
8	Rich Flammability Limit by Volume	0.067
9	Least Autoignition Temperature ( $T_a^\circ$ )	477 K
10	$\frac{h_{fg}^\circ}{RT_b^\circ}$	11.83 where $R = 8.314 \text{ kg/mol K}$
11	Adiabatic Flame Temperature at Lower Flammability Limit	1692 K
12	Density	675 kg/m <sup>3</sup>

13	Heat of Combustion ( $\Delta h_c$ )	44.6 MJ/kg
14	Mass Loss Rate for an Infinite Diameter Pool ( $\dot{m}_{\infty}''$ )	0.101 kg/m <sup>2</sup>
15	Product of Extinction-Absorption Coefficient and the Mean-Beam-Length Corrector ( $\kappa\beta$ )	1.1 m <sup>-1</sup>

**TABLE 1 n-Heptane Parameters**

Notes:

Items 1-10 from SFPE Handbook Section 1-320 (5)

Item 11 from SFPE Handbook Section 1-152 (5)

Items 12-15 from SFPE Handbook Section 2-2 (5)

### **III.D.2. FIRE SIZE:**

The pool fire size had to be wide enough so that the electromagnetic wave would not be transmitted around it. Since the antennas used were 1.282 m (50.5 inches) wide (when transmitting in the horizontal polarization configuration) a pool fire at least this wide was deemed necessary. The laboratory facility (Chesapeake Bay Division of the Naval Research Laboratory) had a square pan 18.89 cm by 18.89 cm (48 inches by 48 inches) by 2.36 cm (6 inches) deep. When placed diagonally, this pan was 26.72 cm (67.88 inches) wide. Therefore, this pan was considered adequate for this experiment.

**Flame Height:** The following are the calculations for the flame height using the pan described above. This information will assist in determining the orientation of the antennas. The height of a pool fire flame is directly related to its pool diameter (which in this case is limited to the pan size). In this case, the pan had a total surface area of 18.89 cm by 18.89 cm (48 inches by 48 inches) or 1.49 square meters (2304 square inches). From the SFPE Handbook<sup>5</sup> (Section 1, Chapter 18), Heskestad's correlation for flame height states:

$$H/D = 3.7Q^{*2/5} - 1.02 \quad [\text{III.1}]$$

Where H is the flame height, D is the diameter of the pool, and Q\* is given by:

$$Q^* = \frac{Q}{\rho_{\infty} C_p T_{\infty} \sqrt{g D D^2}} \quad [\text{III.2}]$$

Where:

$\rho_{\infty}$  = ambient density

$C_p$  = specific heat (ambient) (approximately 1 kJ/kg K)

$T_{\infty}$  = absolute temperature (ambient)

$g$  = gravity (9.8 m/s<sup>2</sup>)

$Q$  = heat release rate

From the SFPE Handbook Table 1-18.1,  $Q^*$  for heptane is approximately 1.2. Inserting this into equation [III.1] yields the following:

$$H/D = 2.96 \text{ or } H = 2.96D \quad [\text{III.3}]$$

This equation assumes a circular pool fire. Since a square pan was used in this experiment, an “equivalent” circular diameter is required. The square pan had a surface area of 1.49 square meters (2304 square inches). The surface area of a generic circle is given by

$$\text{Surface Area} = \Pi \frac{D^2}{4} \quad [\text{III.4}]$$

Setting this equal to our required surface area we get:

$$1.49 = \Pi \frac{D^2}{4} \quad [\text{III.5}]$$

Solving for the diameter  $D$  (in meters) gives the equivalent pool size diameter:

$$D = \sqrt{\frac{4(1.49)}{\Pi}} = 1.38 \text{ meters} \quad [\text{III.6}]$$

Inserting our “equivalent” diameter into equation [III.3] yields a flame height of approximately 4.08 meters (or 13.4 feet).

Actual flame heights could be lower than the calculated due to the following:

- the burning rate may be lower than the mass loss rate due to more fuel leaving the surface than is being burned (SFPE page 1-299).
- the reaction may not go to completion. Complete burning would result in  $\text{CO}_2$  and  $\text{H}_2\text{O}$ , but incomplete burning yields soot particles that remove energy from the fire. This reduces the heat release rate,  $Q$ , which reduces  $Q^*$ , which lowers the  $H/D$  ratio and because  $D$  is constant, results in a lower flame height.

Required Amount of Fuel: The amount of fuel required for each of the tests was dependent on the control/data acquisition software. When the program was executed, it took approximately 3-4 minutes to transmit all the frequencies and record all the data. Therefore, the fire had to last at least this long. The following are the calculations to determine how much fuel is required to create a 18.89 cm by 18.89 cm (48 inch x 48 inch) heptane fire that would last 4 minutes.

The SFPE Handbook<sup>5</sup> Section 2 Chapter 1 entitled "Burning Rates" by Vytenis Babrauskas, expresses the mass loss rate per unit area of a pool fire burning in the open by the following formula:

$$\dot{m}'' = \dot{m}_{\infty}'' (1 - e^{-\kappa\beta D}) \quad [\text{III.7}]$$

where

- $\dot{m}_{\infty}''$  = the mass loss rate for an infinite diameter pool
- $\kappa\beta$  = the product of the extinction-absorption coefficient of the flame ( $\kappa$ ) and the mean-beam-length corrector ( $\beta$ )
- $D$  = the diameter of the pool

From Table III.1 entitled "n-Heptane Parameters":

$$\begin{aligned} \dot{m}_{\infty}'' &= 0.101 \text{ kg/m}^2\text{S} \\ \kappa\beta &= 1.1 \text{ m}^{-1} \end{aligned}$$

and  $D = 1.38$  meters (from the above "equivalent diameter"). Plugging in and solving for the mass loss rate per unit area of a pool fire burning in the open, we get:

$$\dot{m}'' = 0.079 \text{ kg/m}^2\text{S}$$

Since we are interested in a fire that lasts for a minimum of four minutes, or 240 seconds:

$$0.079 \left[ \text{kg} / \text{m}^2 \text{S} \right] \times 240 \left[ \text{S} \right] = 18.96 \left[ \text{kg} / \text{m}^2 \right]$$

Multiplying by the surface area of our pool ( $1.49 \text{ m}^2$  from above) yields:

$$18.96 \left[ \text{kg} / \text{m}^2 \right] \times 1.49 \left[ \text{m}^2 \right] = 28.25 \left[ \text{kg} \right]$$

Dividing the mass of require heptane by its density from Table III.1, we get the required volume:

$$28.25 \left[ \text{kg} \right] \div 675 \left[ \frac{\text{kg}}{\text{m}^3} \right] = 0.042 \left[ \text{m}^3 \right]$$

Converting cubic meters to gallons we get:

$$0.042 \left[ m^3 \right] \times 249.65 \left[ \frac{\text{gallons}}{m^3} \right] = 10.5 \left[ \text{gallons} \right]$$

Therefore, the amount of heptane required to create a pool fire lasting 4 minutes in a pan 48" x 48" is 10.5 gallons.

### **III.D.3. ANTENNA PLACEMENT:**

This experiment consisted of eight separate fire tests. It is important to restate that each test was run twice; once without the fire (baseline) and once with the fire. This was done to provide a means for comparison. The antenna configuration for each fire test was varied in order to obtain information on the transmitted signal. This section describes each of the configurations and the objective of each test.

Before running any of the test, a calculation was made to determine the optimum spacing of the antennas:

The wavelength ( $\lambda$ ) at the low frequency end ( $f = 30$  MHz, where  $c = 3 \times 10^8$  is the speed of light) is:

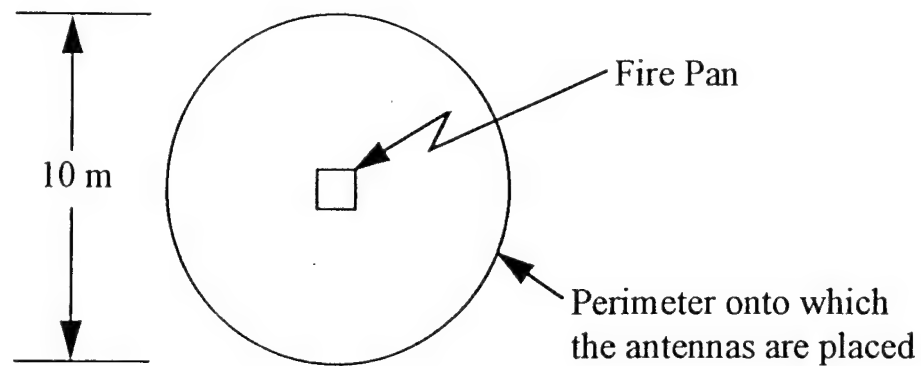
$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{30 \times 10^6} = 10 \text{ meters} \quad [\text{III.8}]$$

At the high frequency end ( $f = 1000$  MHz):

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{1000 \times 10^6} = 0.3 \text{ meters} \quad [\text{III.9}]$$

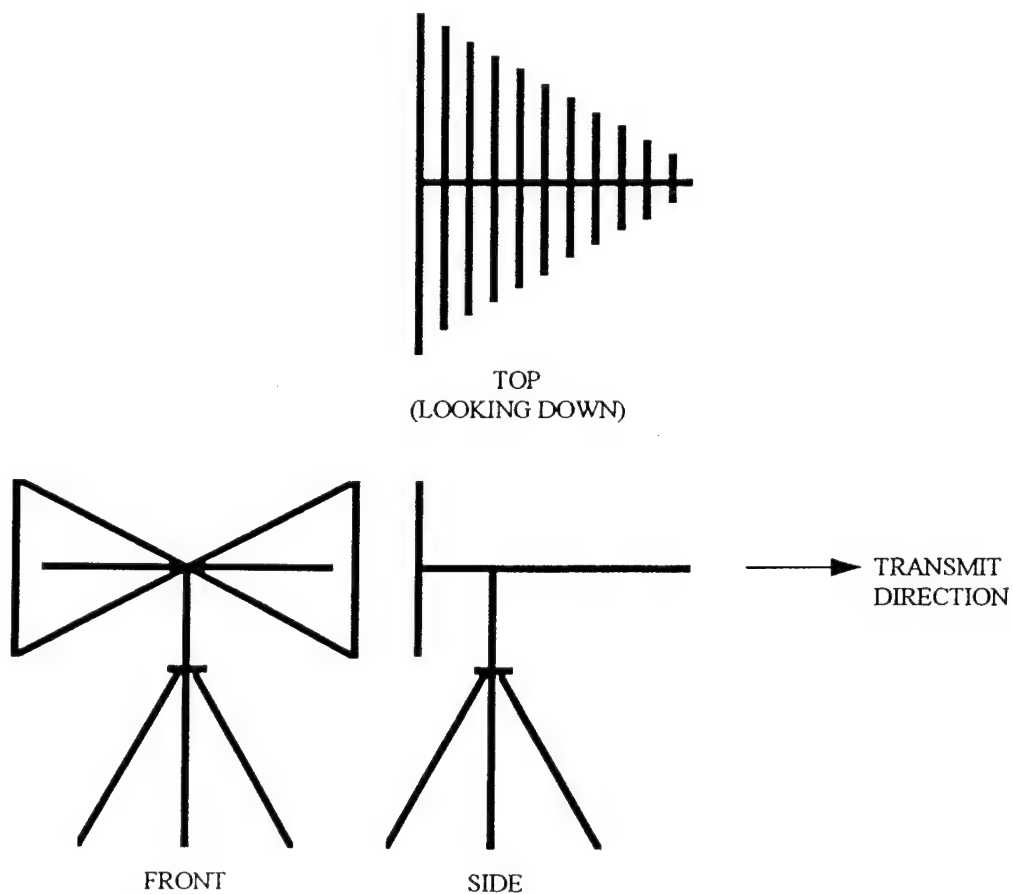
Therefore, in order to acquire the full energy of the entire frequency range of 30 MHz to 1000 MHz, an antenna separation distance of 10 meters was maintained (when transmitting directly through the fire). Figure 4 depicts the general setup.

The height of each antenna was maintained at a minimum in order to ensure transmission through the fire. Since the fire test took place outside, the wind blew the flames erratically from vertical. A low antenna height increased the probability of transmitting through the fire. An antenna height of 9.44 to 11.02 cm (24 to 28 inches) was used in this experiment (limited by the antenna tripod).

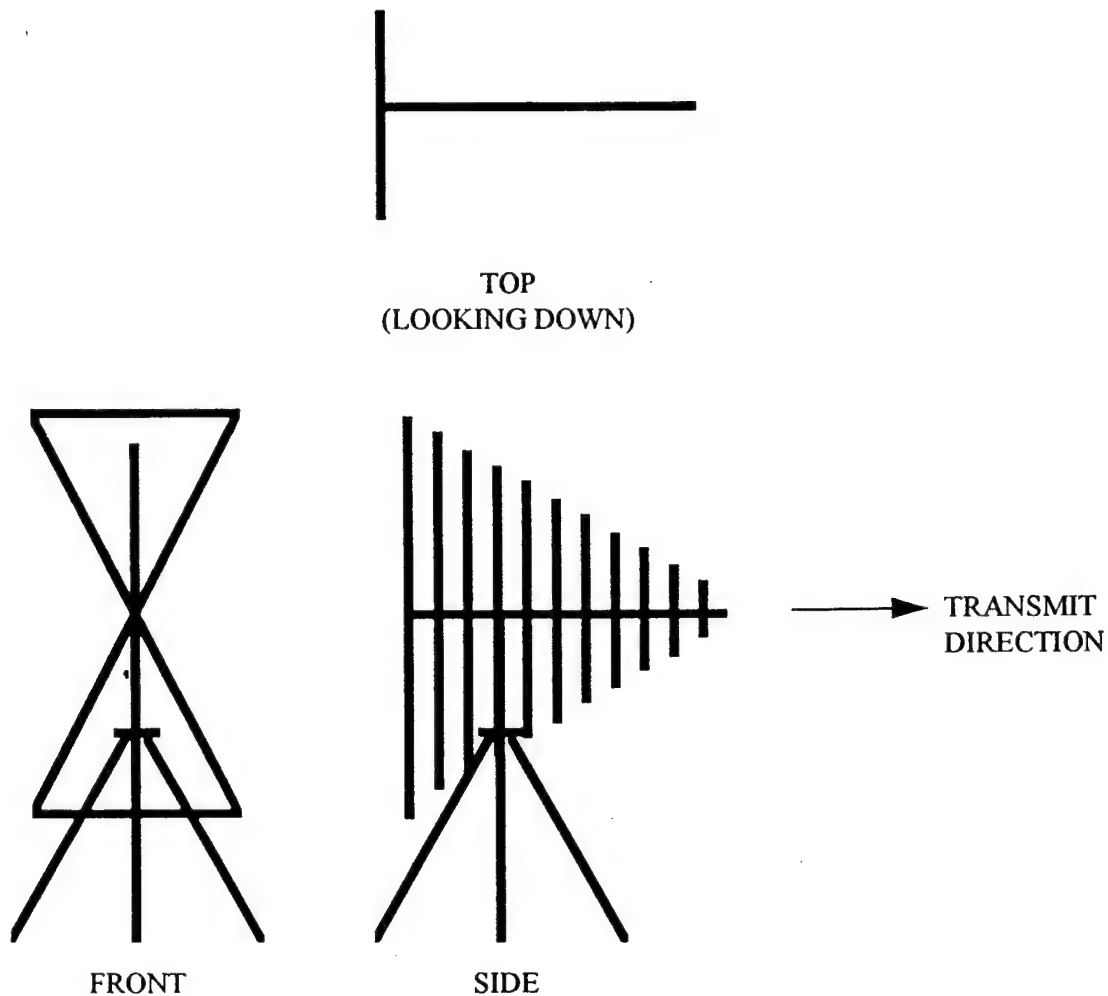


**Figure 4: Antenna Location Perimeter**

The antennas were used to provide either a horizontal or a vertical polarization of the transmitted signal. This was done by setting the antennas in the orientations shown in Figures 5 and 6.



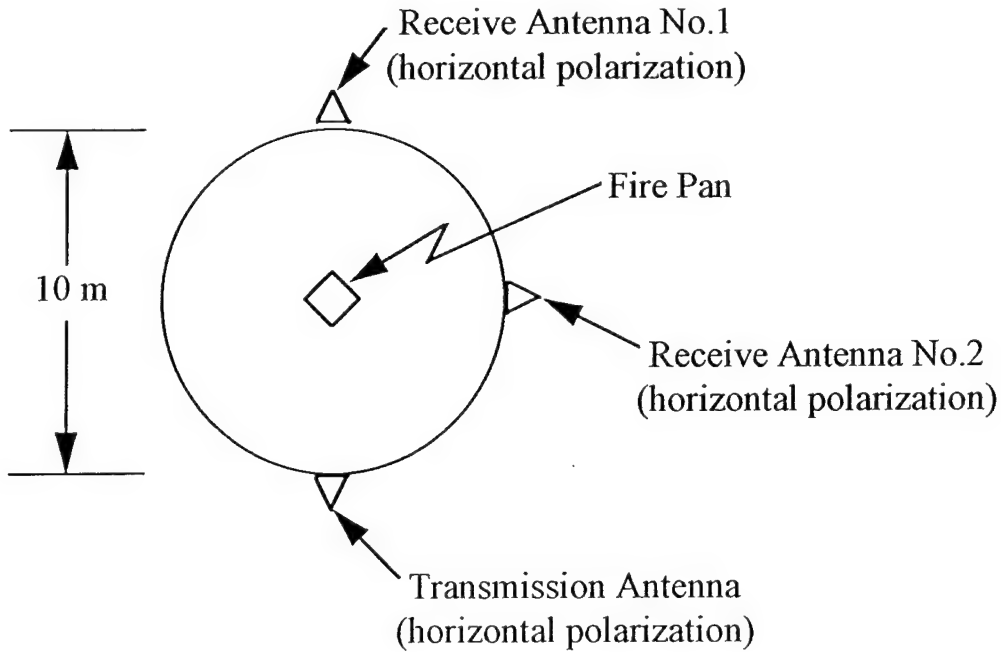
**Figure 5: Horizontal Polarization Antenna Setup**



**Figure 6: Vertical Polarization Antenna Setup**

**Test 1:**

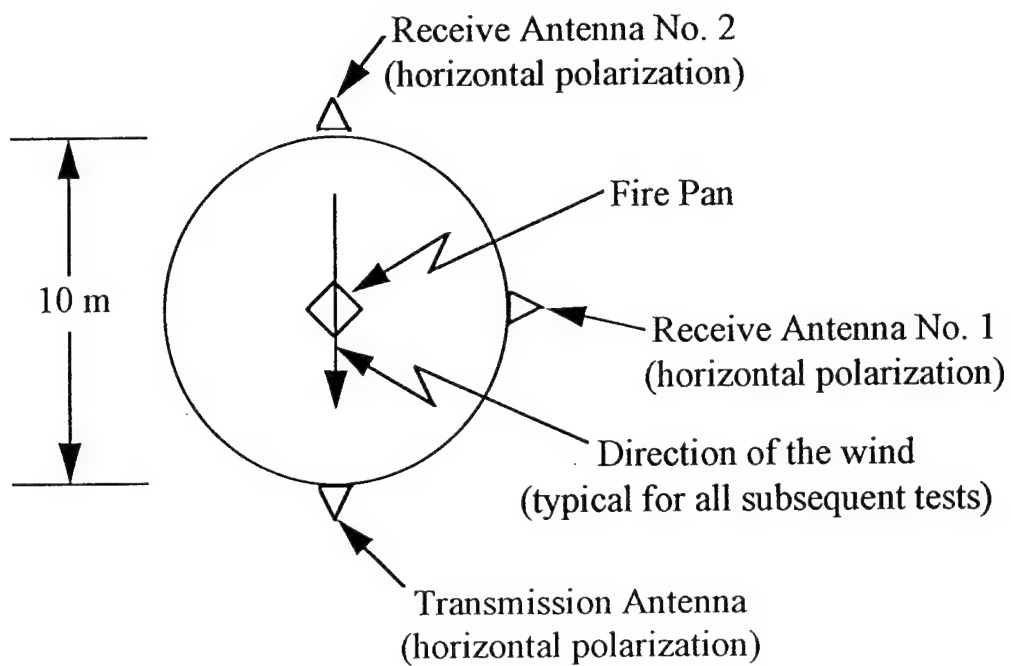
The object of this test was to investigate the effects of a fire on horizontally polarized radio transmission waves. Receive Antenna No. 1 was placed  $180^\circ$  from the Transmission Antenna (horizontally), while Receive Antenna No. 2 was placed at  $90^\circ$  to the transmission (horizontally). Receive Antenna No. 1 was used to measure signal losses/gains while Receive Antenna No. 2 was used to measure reflected power. Figure 7 shows the antenna locations.



**Figure 7: Test 1 Antenna Location**

**Test 2:**

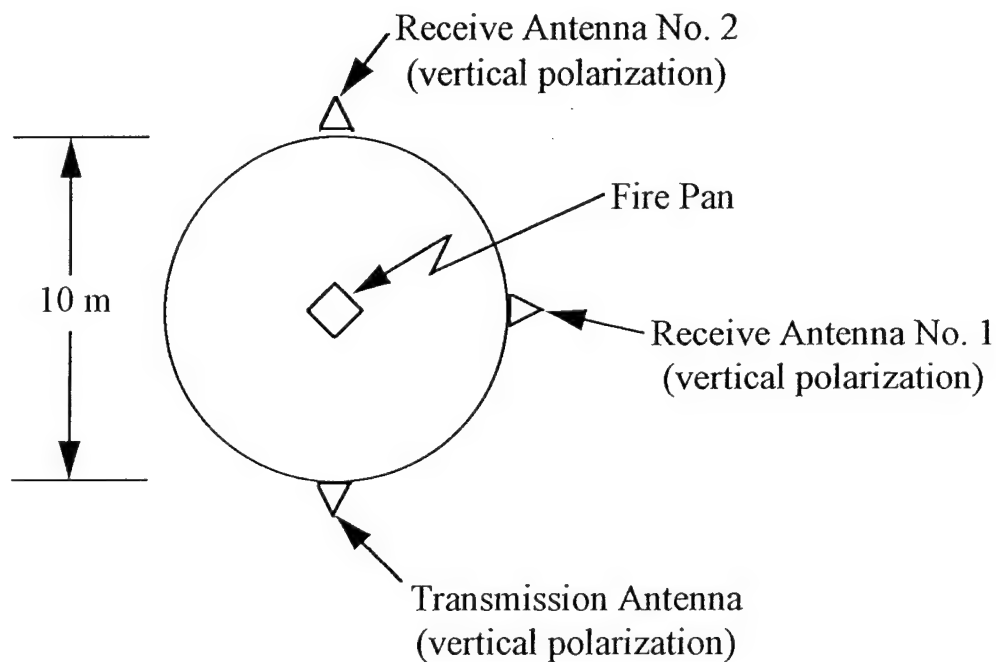
This test was exactly the same as Test 1 except the positions of Receive Antenna No. 1 and Receive Antenna No. 2 were swapped, and the test was rotated so that the transmission was in line with the direction of the wind (in order to increase the probability that transmission through the fire was actually taking place; this method was used for all subsequent tests). In this case, Receive Antenna No. 1 was used to measure reflected power while Receive Antenna No. 2 was used to measure signal losses/gains. Figure 8 depicts the antenna locations.



**Figure 8: Test 2 Antenna Location**

### Test 3:

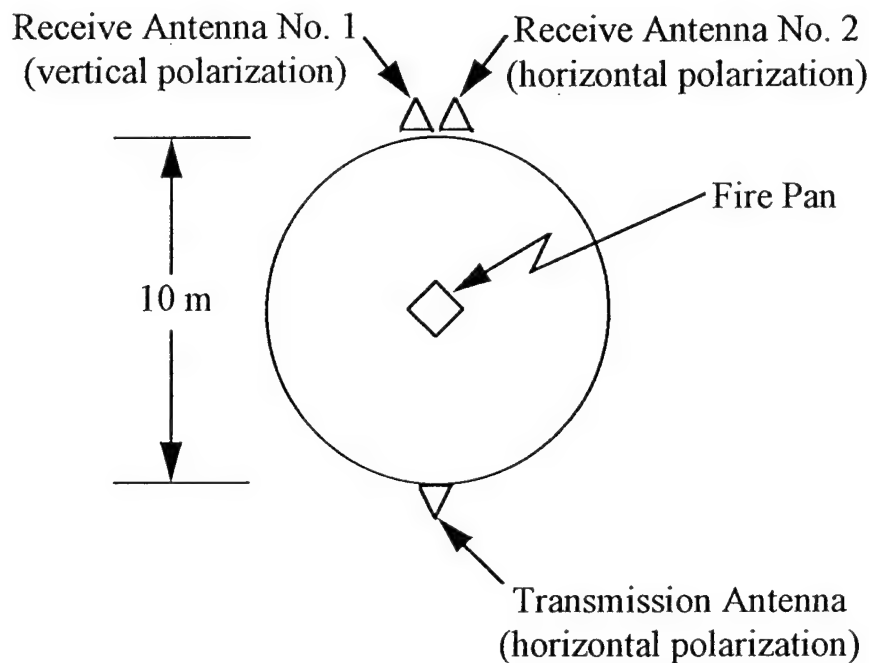
The object of this test was to investigate the effects of a fire on vertically polarized radio transmission waves. Receive Antenna No. 1 was placed  $90^\circ$  from the Transmission Antenna (vertically), while Receive Antenna No. 2 was placed at  $180^\circ$  to the transmission (vertically). Receive Antenna No. 1 was used to measure reflected power while Receive Antenna No. 2 was used to measure signal losses/gains. Figure 9 shows the antenna locations.



**Figure 9: Test 3 Antenna Location**

#### **Test 4:**

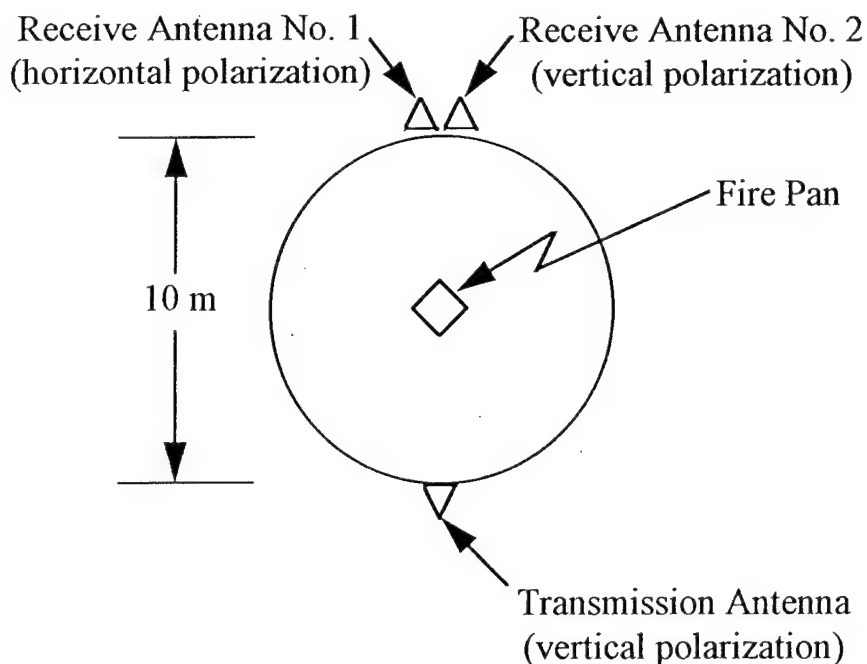
The object of this test was to determine if the fire would rotate a horizontally polarized transmitted wave. If the signal proved to be rotated, this could help explain some losses (if any) when transmitting and receiving in the same polarization. Receive Antenna No. 1 was placed  $180^\circ$  from the Transmission Antenna in the vertical polarization configuration, while Receive Antenna No. 2 was placed at  $180^\circ$  to the transmission in the horizontally polarized configuration. Figure 10 shows the antenna locations.



**Figure 10: Test 4 Antenna Location**

#### **Test 5:**

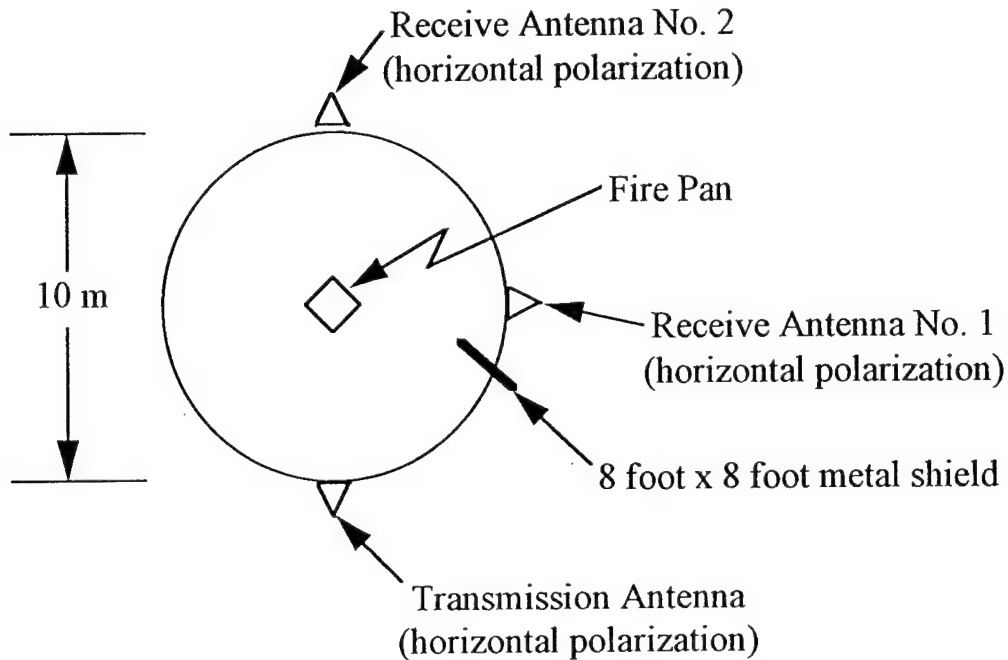
The object of this test was to determine if the fire would rotate a vertically polarized transmitted wave. Receive Antenna No. 1 was placed  $180^\circ$  from the Transmission Antenna in the horizontal polarization configuration, while Receive Antenna No. 2 was placed at  $180^\circ$  to the transmission in the vertically polarized configuration. Figure 11 shows the antenna locations.



**Figure 11: Test 5 Antenna Location**

**Test 6:**

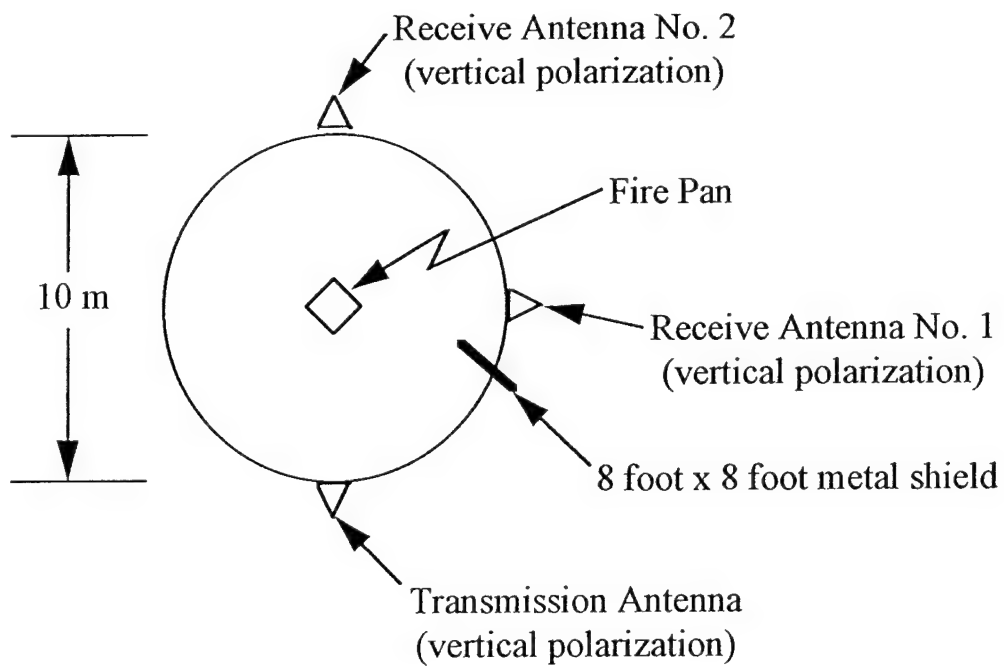
The object of this test was to determine if the fire would reflect or refract a horizontally polarized transmitted wave. Receive Antenna No. 1 was placed  $90^\circ$  from the Transmission Antenna in the horizontal polarization configuration behind a shield, while Receive Antenna No. 2 was placed at  $180^\circ$  to the transmission in the horizontally polarized configuration. The shield was made from two 4 foot by 8 foot pieces of plywood with steel sheet metal lining one side so that the total shield size was 8 feet wide by 8 feet high. Figure 12 shows the antenna locations.



**Figure 12: Test 6 Antenna Location**

**Test 7 & 8:**

The object of this test was to determine if the fire would reflect or refract a vertically polarized transmitted wave. Receive Antenna No. 1 was placed  $90^\circ$  from the Transmission Antenna in the vertical polarization configuration behind a shield, while Receive Antenna No. 2 was placed at  $180^\circ$  to the transmission in the vertically polarized configuration. The same shield was used as that described in Test 6. Shortly after Test 7 was started, the shield fell over. The test was run to completion in order to obtain the data recorded from Receive Antenna No. 2. The data from Receive Antenna No. 1 was not used. The test was repeated as Test 8. Figure 13 shows the antenna locations.



**Figure 13: Test 7 & 8 Antenna Location**

## IV. EXPERIMENTAL RESULTS

Following the data acquisition from the tests described in the previous section, a means of simplifying the data was required. A time domain waveform was created when each of the data points was plotted. It was difficult to extract any useful data from the two waveforms (baseline and with the fire). Therefore, a computer program was written (in National Instruments Labview "G" format - see Appendix B) that would plot both the time domain waveform and its corresponding power spectrum (frequency domain). This allowed a measurement of the peak power received at any given frequency. The power spectrum was developed for both the baseline tests and the fire tests and their peak powers were compared. A loss or gain in electromagnetic power when transmitting through the fire was then noted. These results will be discussed in later sections.

### IV.A. ANALYSIS SOFTWARE DEVELOPMENT

The flow chart shown in Figure 14 corresponds to the data analysis software which provided the power spectrum for each waveform. The first part of the program requests the file containing the data to be converted and the file to store the newly developed peak power (from the power spectrum). The program then cycles through all the frequencies in the file and stores the peak powers in a spreadsheet format (Microsoft Excel).

The program was written in National Instruments Labview software which contains various data signal processing (DSP) subroutines. The Power Spectrum subroutine (used in this experiment) computes the harmonic power content of periodic signals. Since the input to this subroutine was voltage data points, the subroutine expresses the normalized units of the output sequence power spectrum in watts (based on 1-ohm impedance).

From National Instruments, the Power Spectrum  $S_{xx}(f)$  of a function  $x(t)$  is defined as:

$$S_{xx}(f) = X^*(f)X(f) = |X(f)|^2 \quad [IV.1]$$

where:

$$X(f) = F\{x(t)\}$$

and  $X^*(f)$  is the complex conjugate of  $X(f)$

The National Instruments subroutine used in this experiment uses the Fast Fourier Transform (FFT) and the Discrete Fourier Transform (DFT) to compute the Power Spectrum, which is given by:

$$S_{xx} = \frac{1}{n^2} \left| F\{X\} \right|^2 \quad [\text{IV.2}]$$

where:

$S_{xx}$  represents the output sequence Power Spectrum and  
 $n$  is the number of samples in the input sequence  $X$ .

The FFT, by definition, establishes the relationship between a signal and its representation in the frequency domain. The definition of the Fourier transform of a signal  $x(t)$  is

$$X(f) = F\{x(t)\} = \int_{-\infty}^{\infty} x(t) e^{-j2\pi ft} dt \quad [\text{IV.3}]$$

and the inverse Fourier transform of a signal  $X(f)$  is

$$x(t) = F^{-1}\{X(f)\} = \int_{-\infty}^{\infty} X(f) e^{j2\pi ft} df \quad [\text{IV.4}]$$

The discrete representation of the Fourier transform equations can be derived by sampling the Fourier transform pair using the following relationships:

$$\Delta t = \frac{1}{f_s} \Delta f = \frac{f_s}{n} \quad [\text{IV.5}]$$

where:

$\Delta t$  is the sampling interval,  
 $\Delta f$  is the frequency resolution,  
 $f_s$  is the sampling frequency, and  
 $n$  is the number of samples in both the time and frequency domain.

Thus, the discrete transform pair,  $x_i \Leftrightarrow X_k$  is obtained and the discrete Fourier transform is given by:

$$X_k = \sum_{i=0}^{n-1} x_i e^{-j2\pi k i / n} \Delta t \quad [\text{IV.6}]$$

and the inverse by

$$x_i = \sum_{k=0}^{n-1} X_k e^{j2\pi k i / n} \Delta f \quad [\text{IV.7}]$$

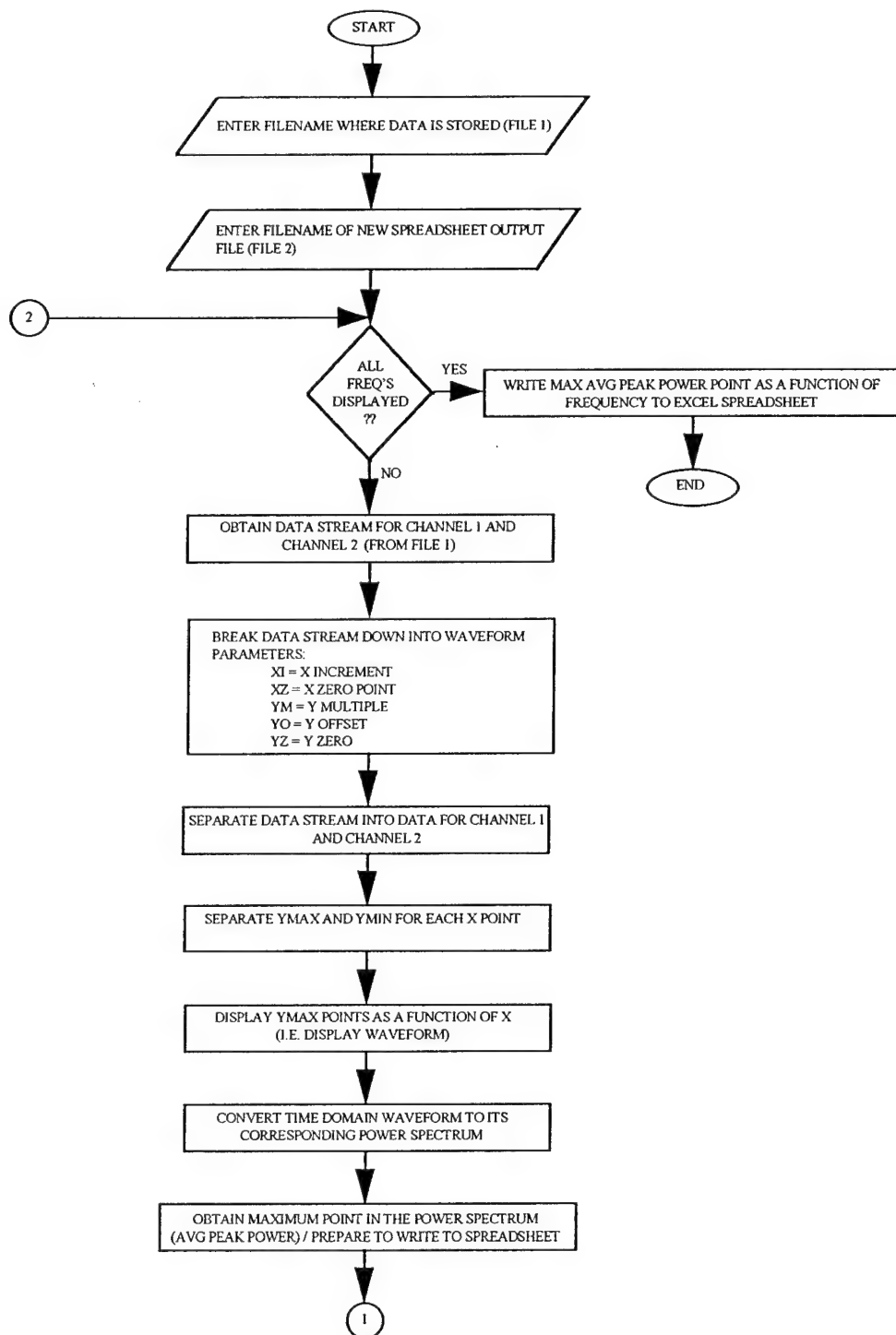
$X_k$  in the above equation represents the amplitude spectral density. By multiplying the right hand side of equation [IV.6] by the frequency resolution  $\Delta f$ , the amplitude spectrum is obtained. This amplitude spectrum is the final form of the DFT and inverse DFT, given by the following equations respectively (note that the DFT is independent of the sampling rate):

$$X_k = \sum_{i=0}^{n-1} x_i e^{-j2\pi k i / n} \text{ for } k = 0, 1, 2, \dots, n-1 \quad [\text{IV.8}]$$

$$x_i = \frac{1}{n} \sum_{k=0}^{n-1} X_k e^{j2\pi k i / n} \text{ for } i = 0, 1, 2, \dots, n-1 \quad [\text{IV.9}]$$

#### **IV.B. DATA ANALYSIS SOFTWARE FLOW CHART**

The following is the flow chart for the data analysis software. This program utilizes the power spectrum analysis subroutine discussed in Section IV.A (see Appendix B for the actual program):



**Figure 14: Data Analysis Software**

#### **IV.C. GENERAL DISCUSSION OF THE PRESENTATION OF RESULTS**

The results for each of the tests are presented in the following sections in chart format. These charts show the gain versus frequency for each of the waveforms in each test (approximately 100 frequencies per test). The gain is defined as the peak power received from the power spectrum when transmitting through the fire, divided by the peak power received from the power spectrum when transmitting the baseline (without a fire). Since two receive antennas were used, two input channels were required for data acquisition. The charts will refer to "CH1" or "CH2" as the channel for data acquisition. The title of each chart first identifies the test (i.e. "TEST 1"); followed by the polarization of the receive antenna (i.e. "HORZ" - horizontal polarization; "VERT" - vertical polarization); followed by the geographic location of the receive antenna (for which the data is shown) in relation to the transmission path (i.e. "@ 90" or "@ 180" means 90 degrees and 180 degrees from the transmission path respectively); followed by the polarization of the transmission signal (i.e. "XMIT HORZ" or "XMIT VERT" equates to a horizontally or vertically transmitted signal respectively).

Some frequency points are not shown due to a problem with the baseline acquisition. During the baseline transmission, some waveforms were either not received or all data points of that waveform were on the lower/upper limit scale of the oscilloscope. When recorded data transmitted through the fire was compared against this data, a false gain was obtained. This problem occurred in only a few frequencies in each test and may have occurred due to impedance matching problems within the transmission line (BNC cables were used with various connection points). The data points shown in each of the tests correspond to the acquisition of the data points when transmitting through the fire compared against the successful data acquisition of the baseline signal.

#### **IV.D. RESULTS OF EXPERIMENTAL TESTING**

The results of the eight tests are presented here. Because of their importance, Tests 4 & 5 are presented first. These tests clearly show that the transmitted signal is rotated when propagating through the fire. This occurred in both the horizontal and vertical polarization cases. This rotation describes one mode of transmission loss and provides evidence that a turbulent hydrocarbon pool fire displays characteristics typically found in plasmas.

The remaining six test are presented for additional information but do not clearly show any significant losses. Signal reflection was not observed and therefore the plasma frequency cannot be determined. It was observed that the signal losses tended to be higher at the upper frequencies suggesting that the smaller wavelengths may interact with small particles within the fire. Signal gains are also shown at various random frequencies. One possible explanation of these gains could be signal phase shifting and energy scattering. These test were not set up to identify phase shifting so definitive conclusions cannot be drawn.

#### IV.D.1. TEST 4 RESULTS:

The object of this test was to determine if the fire would rotate a horizontally polarized transmitted wave. Receive Antenna No. 1 (shown in Fig. 15B below) was placed  $180^\circ$  from the Transmission Antenna in the vertical polarization configuration, while Receive Antenna No. 2 (shown in Fig. 15A below) was placed at  $180^\circ$  to the transmission in the horizontally polarized configuration. Figure 10 in Section III shows the antenna locations (see Appendix D for full size charts):

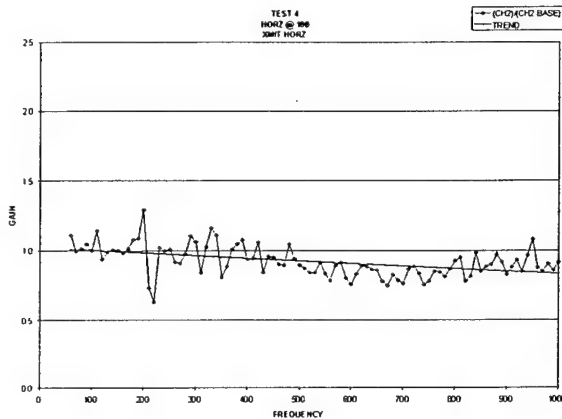


Figure 15A: Receive Antenna #2

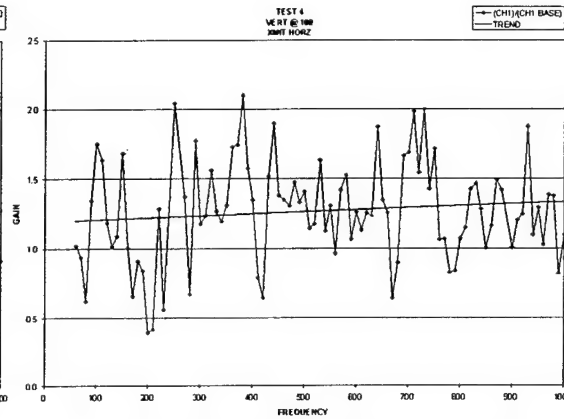


Figure 15B: Receive Antenna #1

This test investigated horizontal signal rotation. Each of the receive antennas was placed at  $180$  degrees to the transmission path, the chart on the left represents the horizontal configuration while the chart on the right represents the vertical configuration. The transmission was in the horizontal polarization.

The horizontally polarized receive antenna showed similar losses when compared against other tests transmitting and receiving at  $180$  degrees in the same polarization. But the vertically polarized antenna showed gains across the entire frequency range. This indicates that some of the horizontally polarized energy was rotated towards the vertical when transmitted through the fire.

#### IV.D.2. TEST 5 RESULTS:

The object of this test was to determine if the fire would rotate a vertically polarized transmitted wave. Receive Antenna No. 1 (shown in Figure 16B) was placed  $180^\circ$  from the Transmission Antenna in the horizontal polarization configuration, while Receive Antenna No. 2 (shown in Figure 16A) was placed at  $180^\circ$  to the transmission in the vertically polarized configuration. Figure 11 in Section III shows the antenna locations (see Appendix D for full size charts):

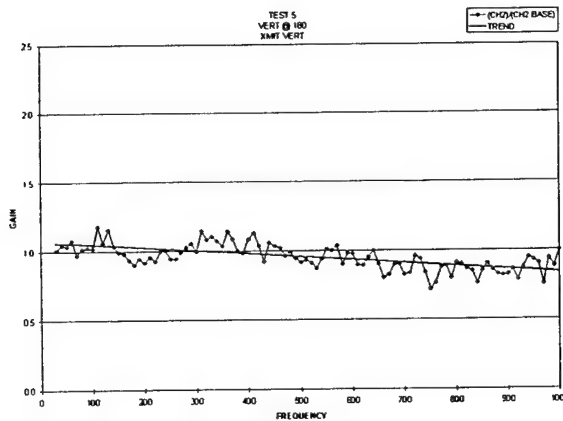


Figure 16A: Receive Antenna #2

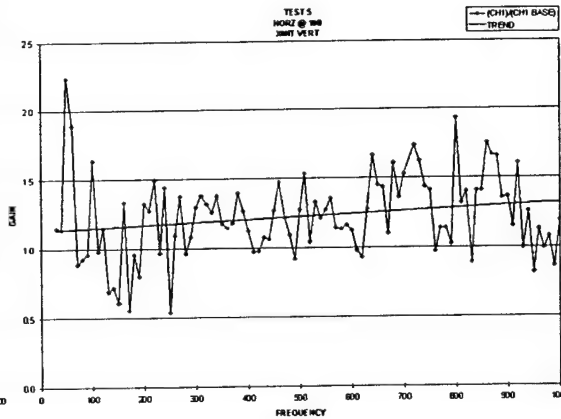


Figure 16B: Receive Antenna #1

This test investigated vertical signal rotation. Each of the receive antennas was placed at 180 degrees to the transmission path, the chart on the left (Fig. 16A) represents the vertical configuration while the chart on the right represents the horizontal configuration. The transmission was in the vertical polarization.

The vertically polarized receive antenna showed similar losses when compared against other tests transmitting and receiving at 180 degrees in the same polarization. But the horizontally polarized antenna (Fig. 16B) showed gains across the entire frequency range. This indicates that some of the vertically polarized energy was rotated towards the horizontal when transmitted through the fire.

#### IV.D.3. TEST 1 RESULTS:

The object of this test was to investigate the effects of a fire on horizontally polarized radio transmission waves. Receive Antenna No. 1 was placed 180° from the Transmission Antenna (horizontally), while Receive Antenna No. 2 was placed at 90° to the transmission (horizontally). Receive Antenna No. 1 was used to measure signal losses/gains while Receive Antenna No. 2 was used to measure reflected power. See Figure 7 in Section III for the antenna locations and orientation.

Figures 17A and 17B show the data received for Test 1 for Receive Antenna No.2 and No.1 (see Appendix D for full size charts):

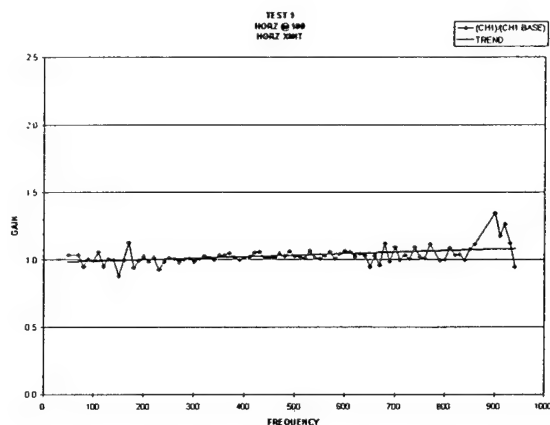


Figure 17A: Receive Antenna #2

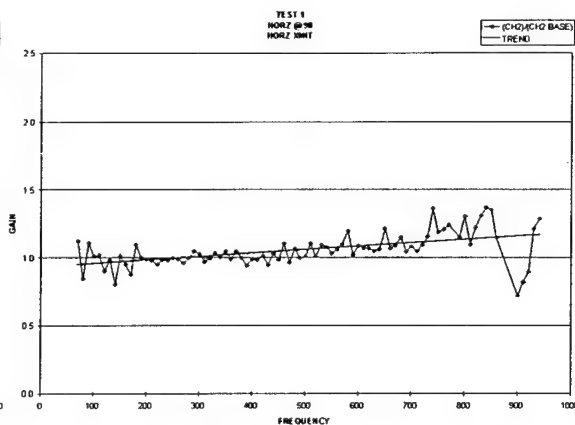


Figure 17B: Receive Antenna #1

This test investigated horizontal polarization. For each receive antenna, an increasing gain was shown with increasing frequency. One explanation for this gain could be the transmission signal was reflected inside the flame causing it to travel along multiple separate paths and eventually arriving at the receive antenna at slightly different times. This experiment was not set up to detect a phase shift; this would require precise timing of the transmission and reception of the signal. It is suspected that if the signal was phase shifted and it traveled along multiple paths, the voltage at the receive antennas would appear to be higher.

The wind in this test was erratic and tended to blow the fire from the vertical. This may have played a part in the increasing signal strength when transmitting through the fire.

#### **IV.D.4. TEST 2 RESULTS:**

This test was the same as Test 1 except the positions of Receive Antenna No. 1 and Receive Antenna No. 2 were swapped, and the test was rotated so that the transmission was in line with the direction of the wind (in order to increase the probability that transmission through the fire was actually taking place; this method was used for all subsequent tests). In this case, Receive Antenna No. 1 was used to measure reflected power while Receive Antenna No. 2 was used to measure signal losses/gains. Figure 8 in Section III depicts the antenna locations (see Appendix D for full size charts)

Figures 18A and 18B show the data received for test #2 for receiver antennas #2 and #1.

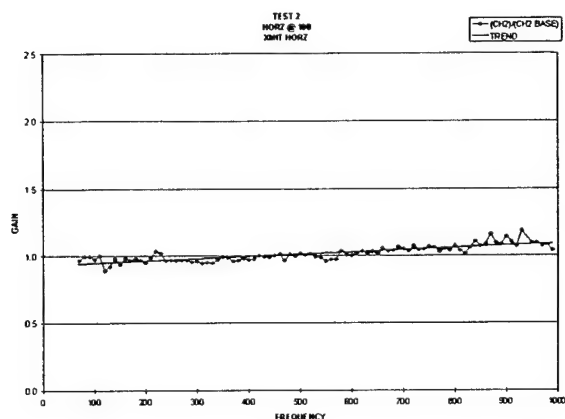


Figure 18A: Receive Antenna #2

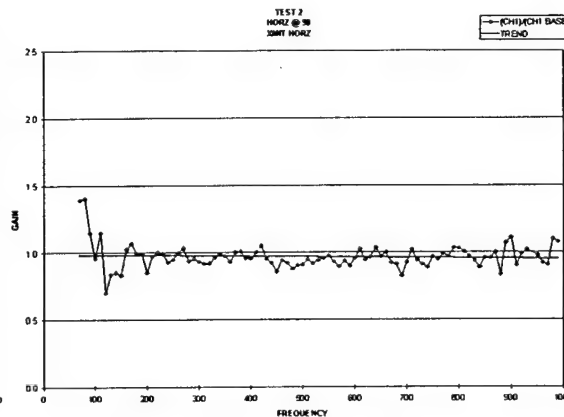


Figure 18B: Receive Antenna #1

When corrected for the direction of the wind, notice that the gain was reduced for the receive antenna #1 positioned 180 degrees from the transmission path. For the receive antenna #2 positioned at 90 degrees from the transmission path, losses were detected. These losses seemed to be steady across the entire frequency range (averaging 5% signal loss).

#### IV.D.5. TEST 3 RESULTS:

The object of this test was to investigate the effects of a fire on vertically polarized radio transmission waves. Receive Antenna No. 1 was placed 90° from the Transmission Antenna (vertically), while Receive Antenna No. 2 was placed at 180° to the transmission (vertically). Receive Antenna #1 was used to measure reflected power while Receive Antenna #2 was used to measure signal losses/gains. Figure 9 in Section III shows the antenna locations (see Appendix D for full size charts). Figures 19A and 19B show the data received for test #3 for receive antennas #1 and #2.

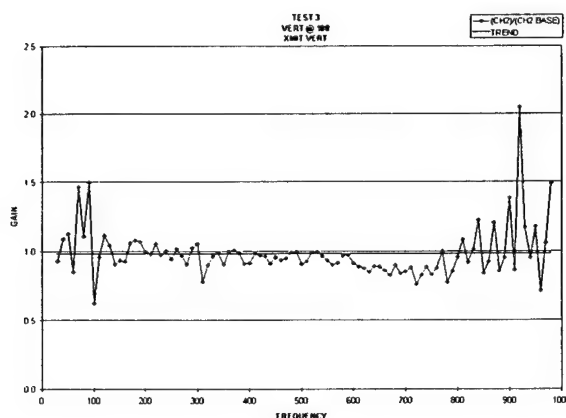


Figure 19A: Receive Antenna #2

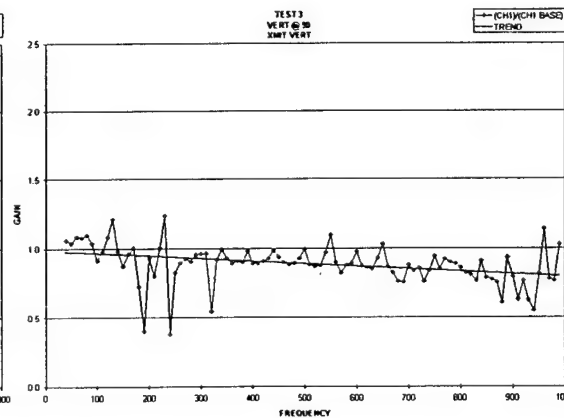


Figure 19B: Receive Antenna #1

Receive antenna #2 positioned at 180 degrees from the transmission path showed losses from approximately 200 MHz through 800 MHz and then displayed erratic measurements from 800 MHz to 1000 MHz. The higher frequencies tended to increase in power received as shown

above. Receive antenna #1 placed at 90 degrees from the transmission path showed increasing signal losses (Fig. 19B) with increasing frequency. This was probably due to the fire absorbing or reflecting power away from the antenna.

#### **IV.D.6. TEST 6 RESULTS:**

The object of this test was to determine if the fire would reflect or refract a horizontally polarized transmitted wave. Receive antenna No. 1 was placed 90° from the Transmission Antenna in the horizontal polarization configuration behind a shield, while Receive Antenna No. 2 was placed at 180° to the transmission in the horizontally polarized configuration. The shield was made from two 1.21 m (4 feet) by 2.43 m (8 feet) pieces of plywood with steel sheet metal lining one side so that the total shield size was 2.43 m (8 feet) wide by 2.43 m (8 feet) high. Figure 12 in Section III shows the antenna locations (see Appendix D for full size charts). Figures 20A and 20B show the received data for test #3 for receive antennas #1 and #2.

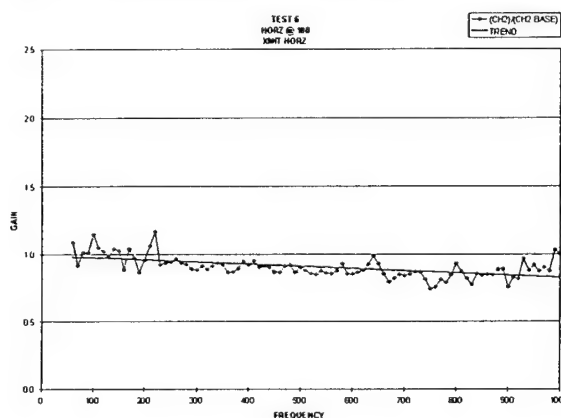


Figure 20A: Receive Antenna #2

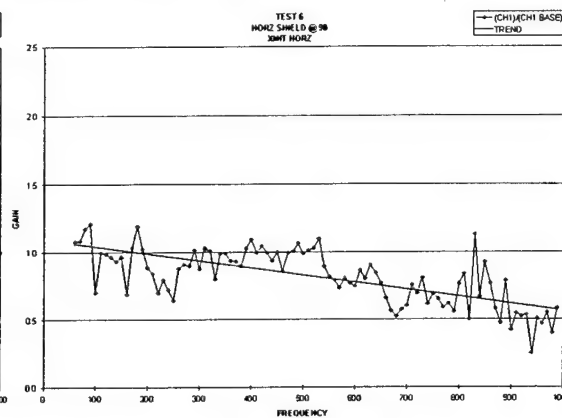


Figure 20B: Receive Antenna #1

The transmission signal was horizontally polarized. Figure 20A shows the data from antenna #2 located 180 degrees from the transmission path. These results are similar to the results shown in Test 4 for the horizontally polarized test - increasing losses with increasing frequency. Antenna #1 located at 90 degrees and shielded from the transmission signal showed some gains (Fig. 20B) up to approximately 530 MHz and then losses for the higher frequencies (except for frequencies around 830 MHz). Reflection from the fire would show a gain in the power received on the antenna behind the shield.

#### **IV.D.7. TEST 7 RESULTS:**

The object of this test was to determine if the fire would reflect or refract a vertically polarized transmitted wave. Receive Antenna #1 was placed 90° from the Transmission Antenna in the vertical polarization configuration behind a shield, while Receive Antenna #2 was placed at 180° to the transmission in the vertically polarized configuration. The same shield was used as that described in Test 6. Shortly after the fire was ignited, the shield fell over. The test was run to completion in order to obtain the data recorded from Receive Antenna #2. The data from Receive Antenna #1 was not used. Figure 13 in Section III shows the antenna locations (see

Appendix D for full size charts). Figure 21 shows the data received for test 6 for receive antenna #2.

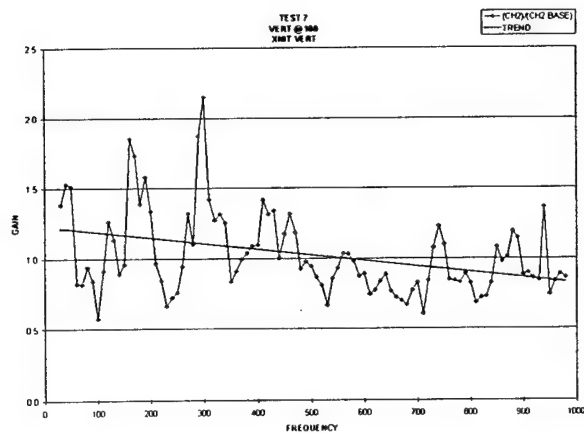


Figure 21: Receive Antenna #2

The results of this test should have been similar to those received in Test 3. More gain was obtained in the lower frequencies in this test than Test 3. This was probably due to the metallic shield that was blown over by the wind. The shield fell so that the metal was facing up and therefore may have acted as a reflector. Any energy directed at the shield may have been reflected to this antenna and subsequently increased the signal strength at the lower frequencies.

### III.D.8. TEST 8 RESULTS

Test 8 is a repeat of Test 7 with the shield fastened more securely to prevent it from falling. Figures 22A and 22B show the data received for test #8 for receive antennas #1 and #2. Figure 13 shows the antenna locations (see Appendix D for full size charts).

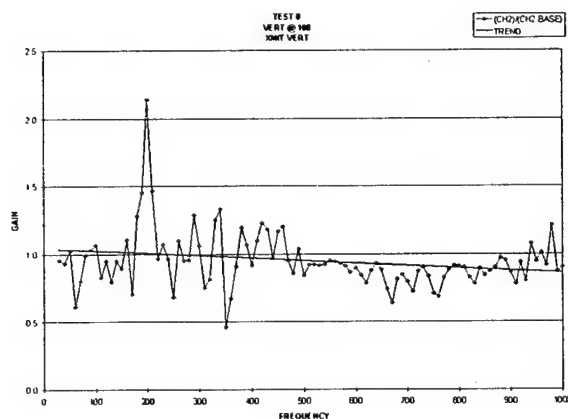


Figure 22A: Receive Antenna #2

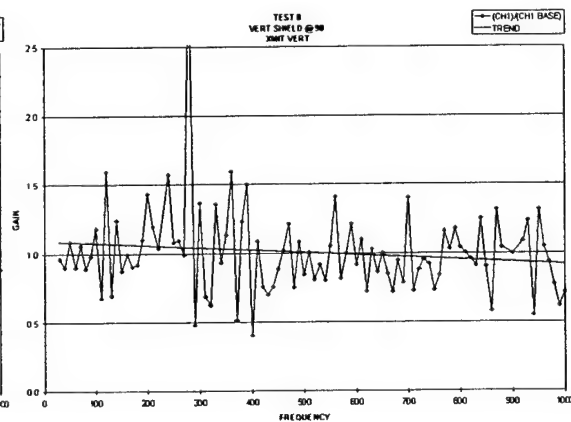


Figure 22B: Receive Antenna #1

Figure 22A shows the data from receive antenna #2 located 180 degrees from the transmission path. The results show losses at the higher frequencies (similar to Test 3). A power spike occurred at 200MHz. This did not occur in the vertically polarized Test 3. Data from antenna #1, located behind the shield, is shown in Fig. 22B. Erratic gains and losses can be seen throughout the frequency range. A spike of approximately 300% signal gain was noted at a frequency of 280 MHz.

## V. CONCLUSIONS

The goal of this experiment was to investigate the losses of an electromagnetic wave when transmitted through a fire. The fire itself was created to simulate a typical hydrocarbon pool fire that may occur on Naval vessels. This experiment has shown a hydrocarbon pool fire rotates both a vertically and a horizontally polarized electromagnetic signal. This is evident from Test 4 and 5. When transmitting in one polarity, a decrease in signal strength was measured for the same polarity, and an increase in signal strength was measured in the opposite polarity. Figure 23 describes the mechanism of signal rotation. Other losses come into play (energy absorption by particles within the fire) so the vector resolutions will not sum directly as shown.

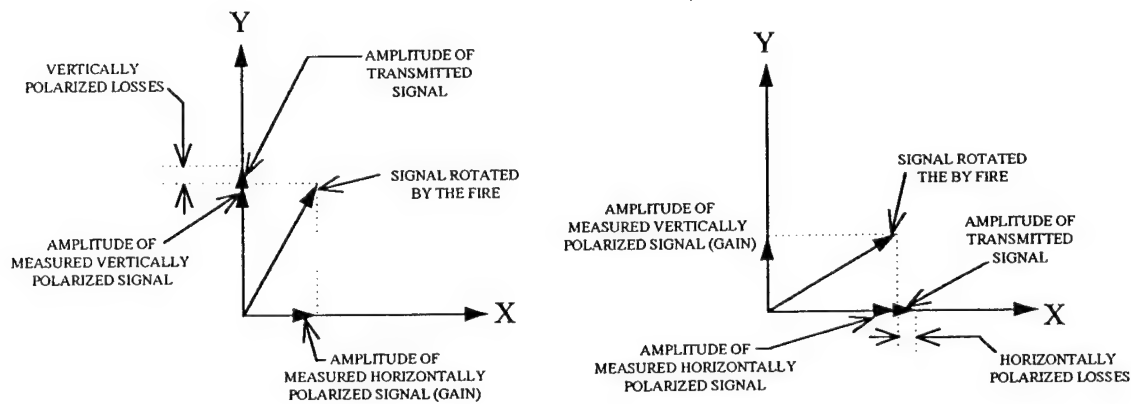


Figure 23: The Mechanism of Signal Rotation

The rotation of the signal shown in this experiment is common in plasmas and is referred to as Faraday Rotation<sup>[6]</sup>. This experiment shows that a large scale hydrocarbon fire displays the characteristics of a plasma. The result shown here are merely qualitative and provide a direction for future study to determine, for example, the amount of rotation. Further testing is also required in order to determine if all plasma characteristics can be applied to large scale fires. The determination of a plasma frequency would be of considerable interest in that this information would provide details on the concentration of electrons or ions within the fire. In addition, this information may be used to provide better communication around (and through) a fire, or possibly lead to a new fire detection mechanism. Also, how is RF communications affected by airborne soot during a fire and by a buildup of soot after a fire. This information could determine the best operating frequencies for use in damage control operations and how communications could be improved during sooty fire episodes.

## VI. RECOMMENDATIONS FOR FUTURE STUDY

This experiment has provided some insight to the electromagnetic properties of a hydrocarbon pool fire, but future testing is still required to provide a complete understanding of all the signal losses and/or gains.

The following are recommendations for future study:

1. This experiment did not test for the phase shifting of a signal when transmitted through a fire. A test that measured phase shift would help describe some of the gains shown in this experiment. Does a portion of the signal get reflected multiple times within the fire and arrive at the receive antenna at a later time than the incident signal?
2. When a signal is reflected from a fire, is it omnidirectional? Due to cost constraints, only two antennas were used in this experiment to receive the transmitted signal. The antennas were placed at 90 and 180 degrees from the incident transmission path. A better method would be to have multiple receive antennas placed around the fire. In this experiment, it is assumed that the antenna placed at 90 degrees to the fire (behind a shield) only received a portion of the reflected signals; however, the fact that any signal was reflected was deemed important. Future studies should try to explain the mechanism of this reflection.
3. Since the Navy uses specific frequencies to communicate for damage control (in a fire scenario), future testing should focus on a more narrow frequency range corresponding to the communication systems proposed to be used for this purpose. This experiment covered a wide frequency range (50 MHz to 1000 MHz) with a frequency interval of 10 MHz. If the plasma frequency, the frequency at which the plasma completely reflects a signal, lies between the 10 MHz intervals it may not be detected. A smaller interval (1 MHz) would provide more resolution in determining the plasma frequency. Also, the test should be set up so the highest frequency is transmitted first. The frequency is then decremented until the plasma frequency is detected. Frequencies above the plasma frequency will generally pass through the plasma (fire) as shown in this experiment.
4. The quantitative amount of signal rotation should be measured. This will require more sophisticated antennas.
5. Various fuels should be used. This experiment used heptane as the fuel but a comparison of kerosene, diesel, jet fuel, gasoline would be of great interest.
6. Future tests should attempt to provide a blockage from the wind. This would allow the fire plume to rise vertically. Once this is accomplished, variation of the antenna transmission height would provide information about the fire. Is a signal attenuated more when transmitted through the reaction zone low in the fire, or do soot particles higher in the plume play a larger role?

7. How are radio frequency (RF) signals affected in confined shipboard spaces? What is the roll of soot, water and reflective surfaces on communications in damage control environments?

## **VII. REFERENCES**

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3. Websters New Dictionary and Thesaurus, Windsor Court, New York, 1989
4. Carhart, H. and Williams, F., "The Ex-Shadwell - Full Scale Fire Research and Test Ship", NRL Memo Report 6074, Sept. 1992.
5. SFPE Fire Protection Handbook
6. Kong, Jin Au, "Electromagnetic Wave Theory", John Wiley and Sons, 1986

## **VIII. ADDITIONAL READING:**

1. NFPA Fire Protection Handbook
2. Street, T., "Feasibility of Implementing a Network for Repair Locker #2 Area of Coverage Using RF Communications: Emissions Testing", Naval Research Laboratory, 2 September 1994
3. Street, T., "Wireless, Spread Spectrum, Low Level RF, DC Communications Network for Repair #2, and the Submarine Mockup Area on Ex-USS SHADWELL", Naval Research Laboratory, 22 November 1995
4. ANSI C63.2, "American National Standards Institute Standard for Instrumentation - Electromagnetic Noise and Field Strength, 10 kHz to 40 GHz - Specifications"
5. ANSI C63.4, "American National Standards Institute Standard for Electromagnetic Compatibility - Radio-Noise Emissions from Low Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz - Methods of Measurement"
6. ARP 958, "Society of Automotive Engineers - Electromagnetic Interference Measurement Antennas; Standard Calibration Requirements and Methods"

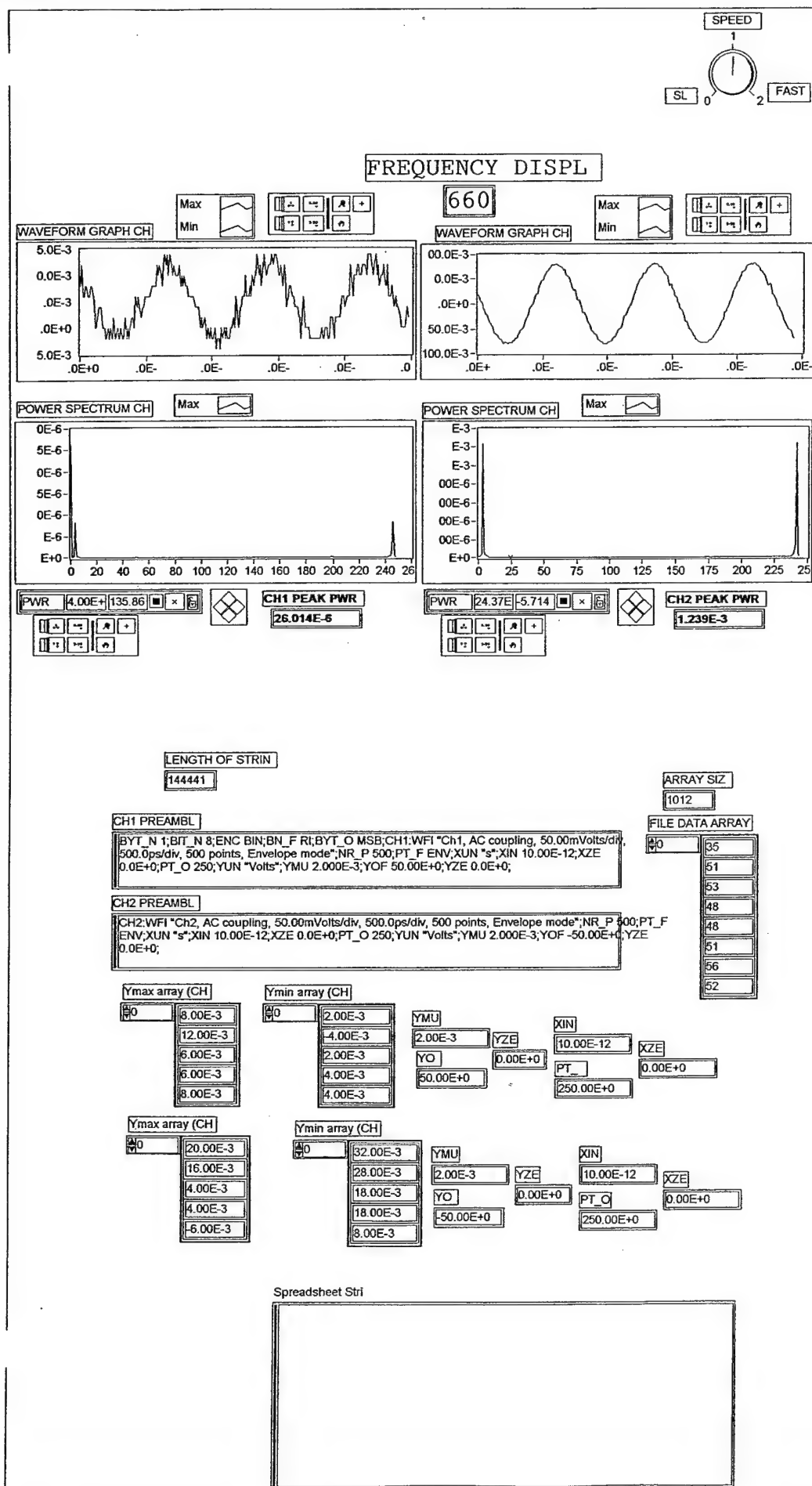
7. Drysdale, Dougal, "An Introduction to Fire Dynamics", John Wiley and Sons, 1985
8. Eggleston, Lester A., "Fire Defense Systems Analysis", Southwest Research Institute, San Antonio, Texas, 1969
9. Glassman, I., "Combustion", Academic Press, New York, 1977
10. Hays, J.B., "Protecting Communications Systems from EMP Effects of Nuclear Explosions", IEEE Spectrum, 1964
11. International Union of Radio Science (URSI), "Nuclear Electromagnetic Pulse (EMP) and Associated Effects", August 1984
12. Johnson, M. and Lippman, B., "Electromagnetic Signals from Nuclear Explosions in Outer Space", The Physical Review, 1 August 1960
13. Jonas, L. and Steel, J., "Energy Fields for Fire Extinguishment", Hughes Associates, Wheaton, MD, August 1990
14. Karzas, W.J. and Latter, R., "Electromagnetic Radiation from a Nuclear Explosion in Space", The Physical Review, 15 June 1962
15. Military Standard 461D, "Requirements for the Control of Electromagnetic Interference Emissions and Susceptibility", Department of Defense, USA, 1993
16. Military Standard 462D, "Measurement of Electromagnetic Interference Characteristics", Department of Defense, USA, 1993
17. Military Standard 45662, "Calibration Systems Requirements", Department of Defense, USA

## **APPENDIX A**

### **DATA ACQUISITION/CONTROL SOFTWARE**

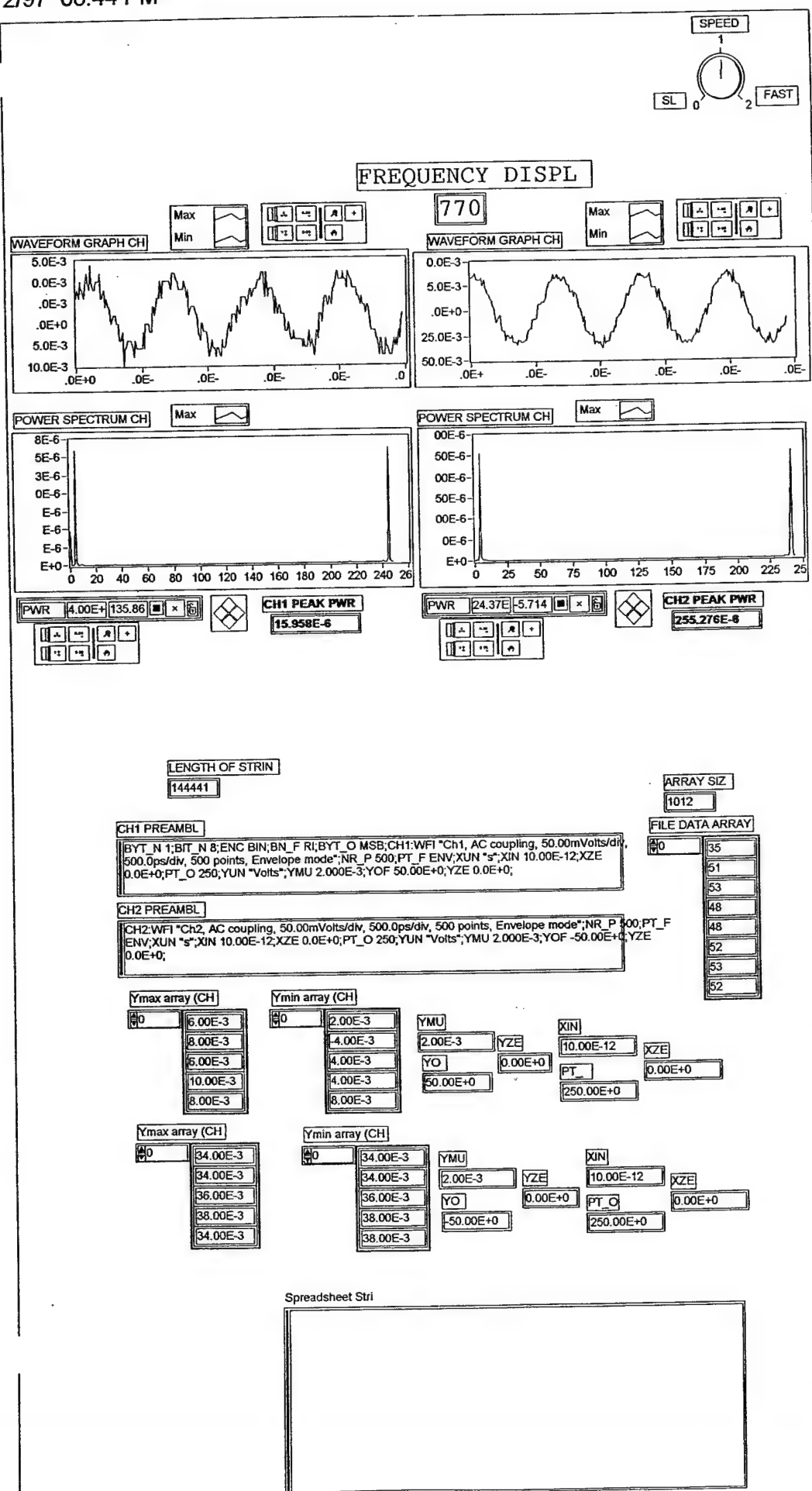


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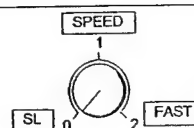


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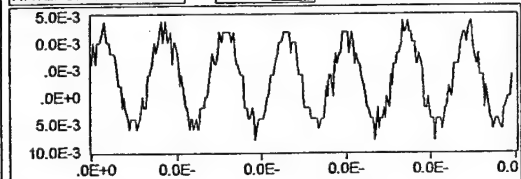
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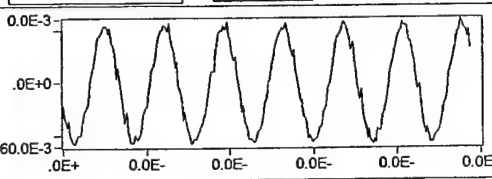
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140

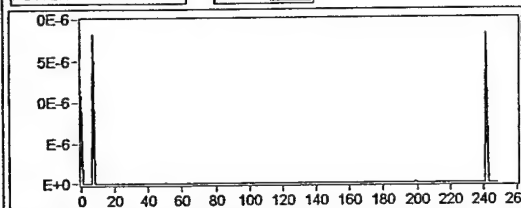
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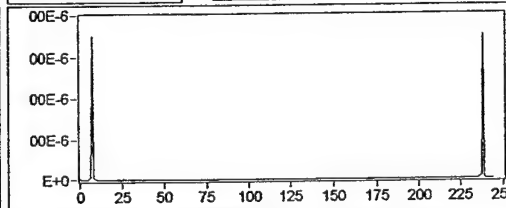
WAVEFORM GRAPH CH



POWER SPECTRUM CH



POWER SPECTRUM CH



PWR 4.00E+135.86



CH1 PEAK PWR

18.138E-6

PWR 24.37E-5.714



CH2 PEAK PWR

702.996E-6

LENGTH OF STRIN

144441

ARRAY SIZ

1012

CH1 PREAMBL

BYT\_N 1;BIT\_N 8;ENC BIN;BN\_F RI;BYT\_O MSB;CH1:WFI \*Ch1, AC coupling, 50.00mVolts/div, 5.000ns/div, 500 points, Envelope mode\*;NR\_P 500;PT\_F ENV;XUN \*s\*;XIN 100.0E-12;XZE 0.0E+0;PT\_O 250;YUN \*Volts\*;YMU 2.000E-3;YOF 50.00E+0;YZE 0.0E+0;

CH2 PREAMBL

CH2:WFI \*Ch2, AC coupling, 50.00mVolts/div, 5.000ns/div, 500 points, Envelope mode\*;NR\_P 500;PT\_F ENV;XUN \*s\*;XIN 100.0E-12;XZE 0.0E+0;PT\_O 250;YUN \*Volts\*;YMU 2.000E-3;YOF -50.00E+0;YZE 0.0E+0;

FILE DATA ARRAY

35
51
53
48
48
50
52
51

Ymax array (CH)

6.00E-3
10.00E-3
6.00E-3
10.00E-3
10.00E-3

Ymin array (CH)

2.00E-3
4.00E-3
0.00E+0
2.00E-3
6.00E-3

YMU

2.00E-3

XIN

100.00E-12

YZE

0.00E+0

XZE

0.00E+0

YO

50.00E+0

PT

250.00E+0

Ymax array (CH)

-22.00E-3
-32.00E-3
-42.00E-3
-36.00E-3
-50.00E-3

Ymin array (CH)

-6.00E-3
-24.00E-3
-26.00E-3
-28.00E-3
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YMU

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XIN

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YZE

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XZE

0.00E+0

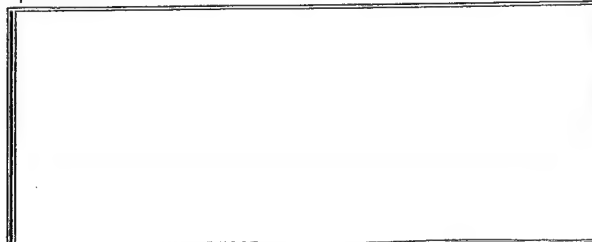
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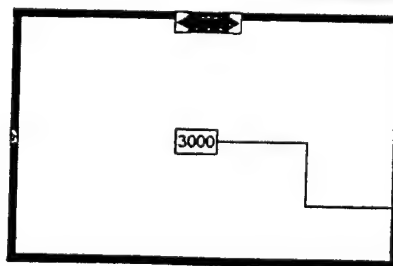
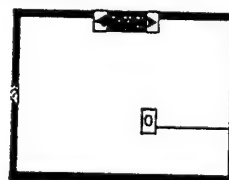
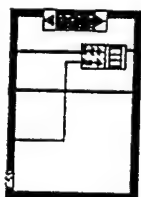
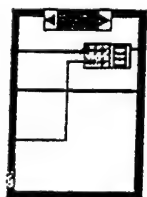
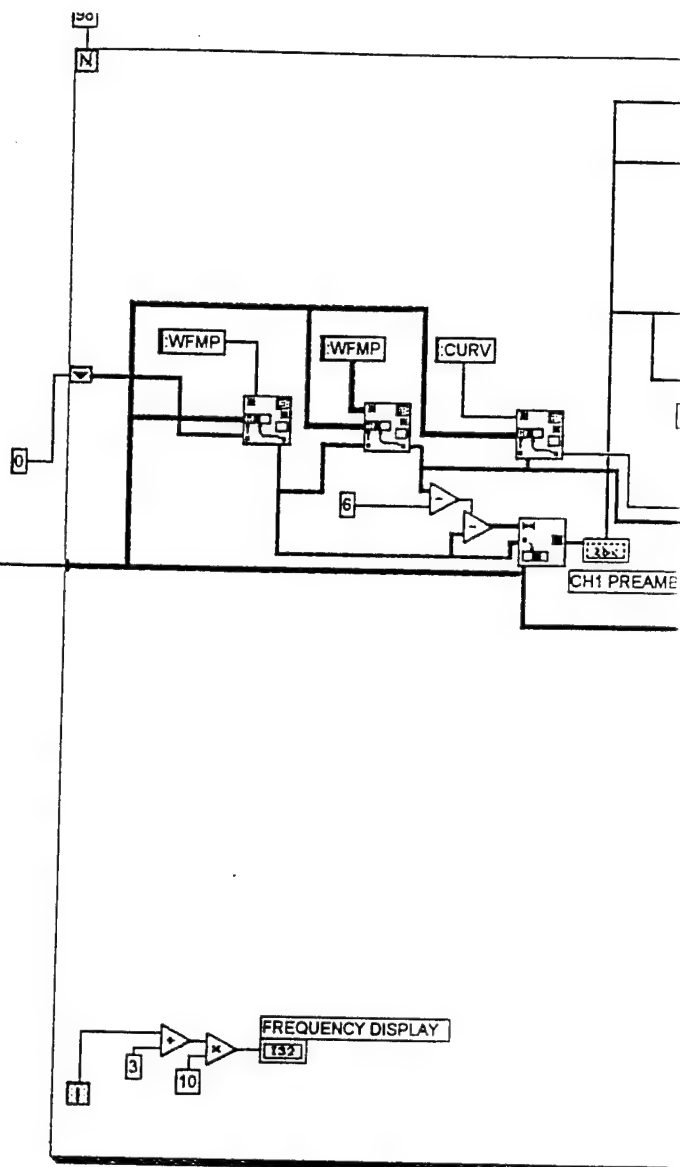
50.00E+0

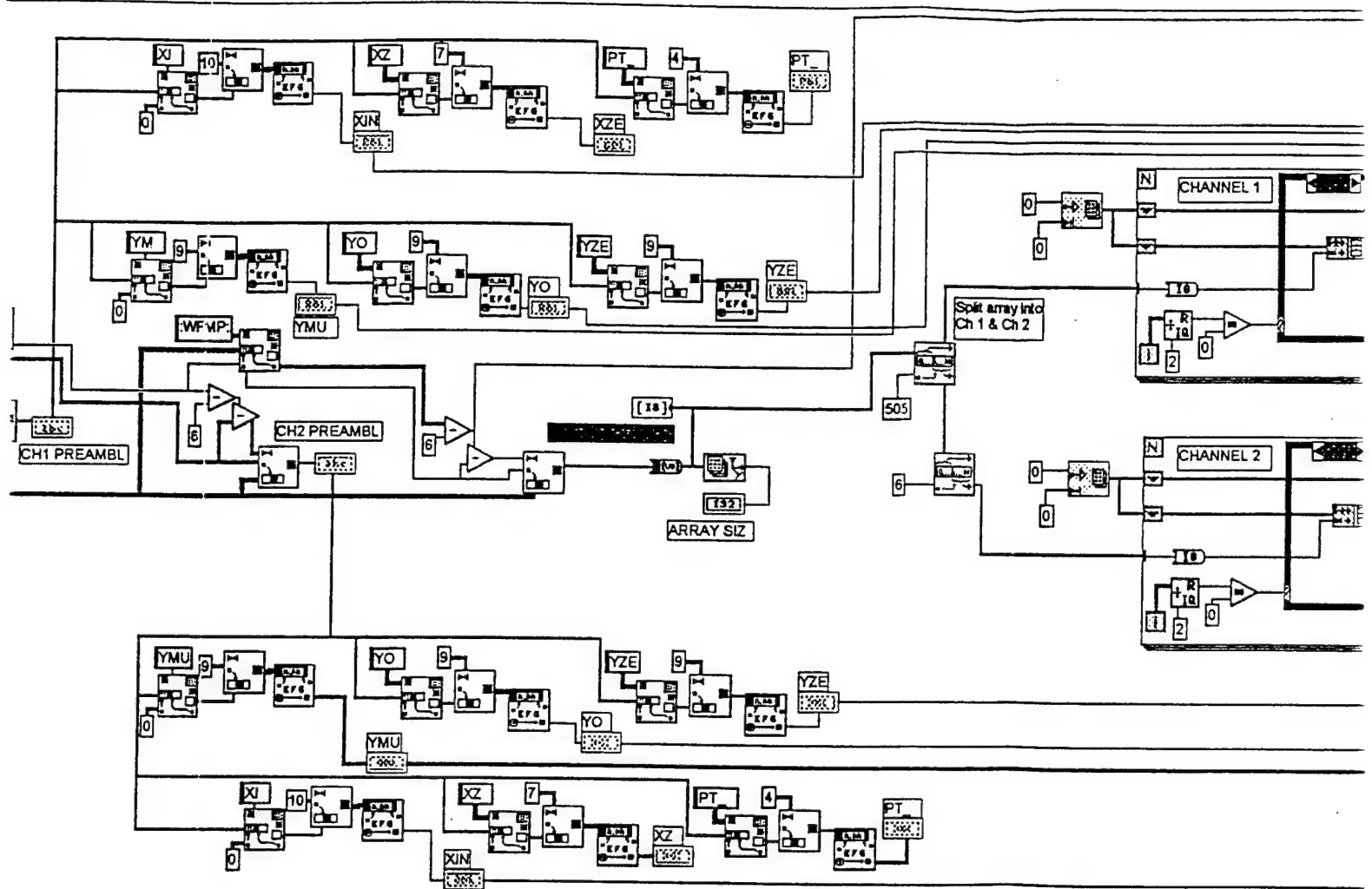
PT

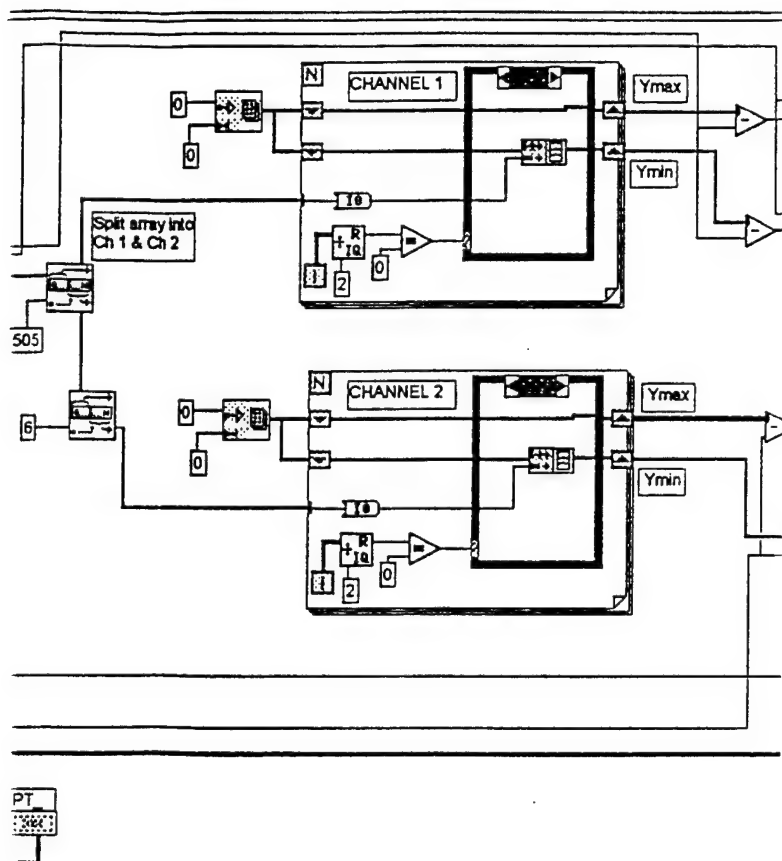
250.00E+0

Spreadsheet Stri



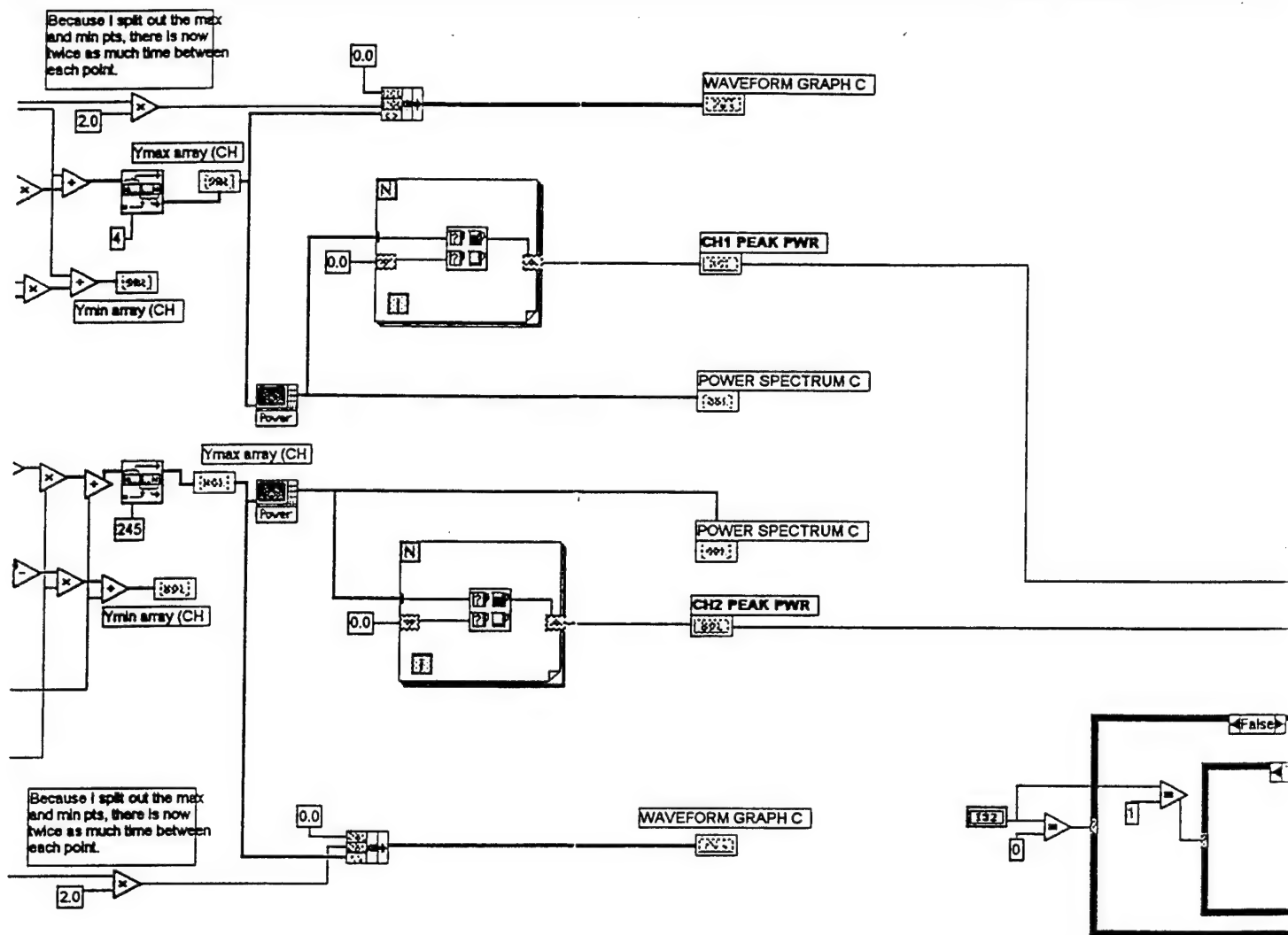




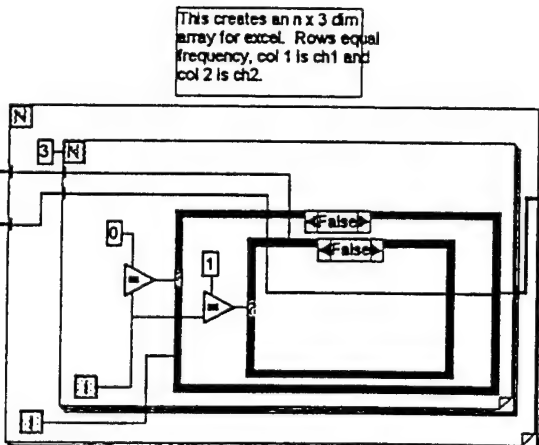
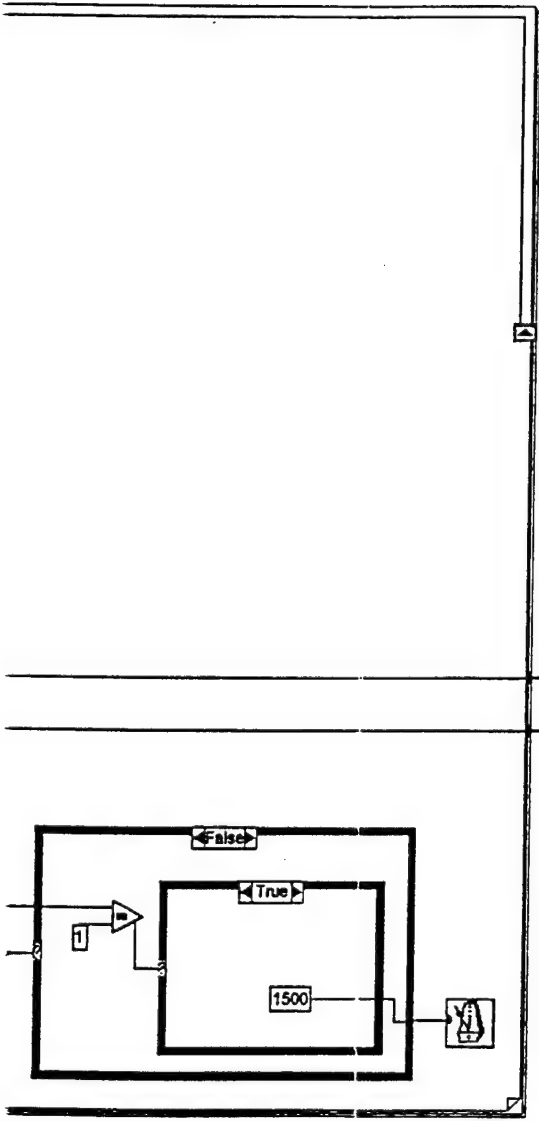


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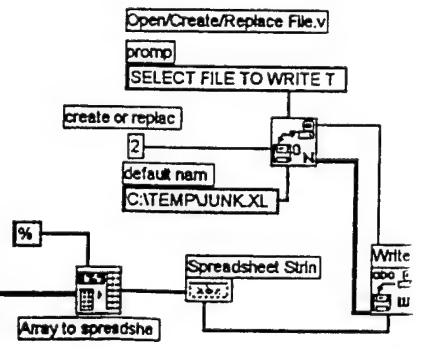
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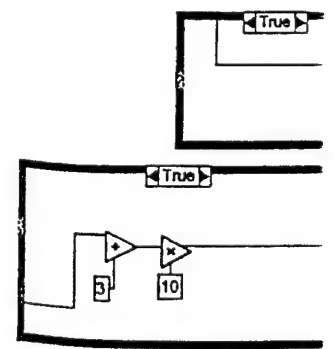
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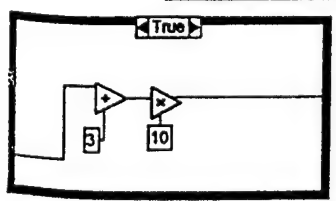
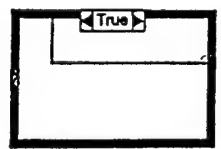
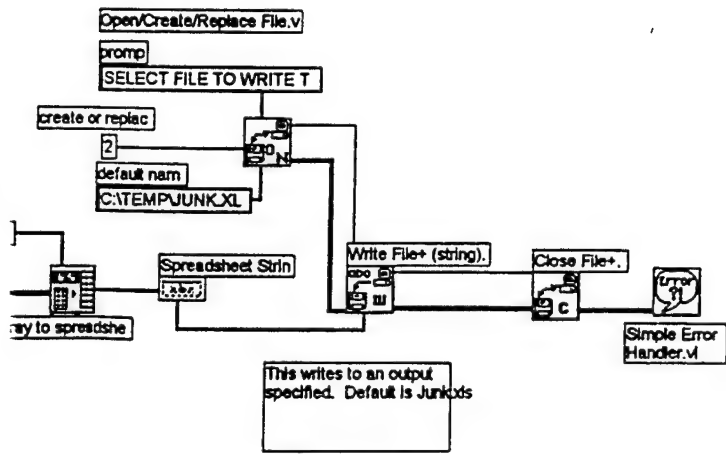
This creates an n x 3 dim array for excel. Rows equal frequency, col 1 is ch1 and col 2 is ch2.



This writes to an specified. Defau

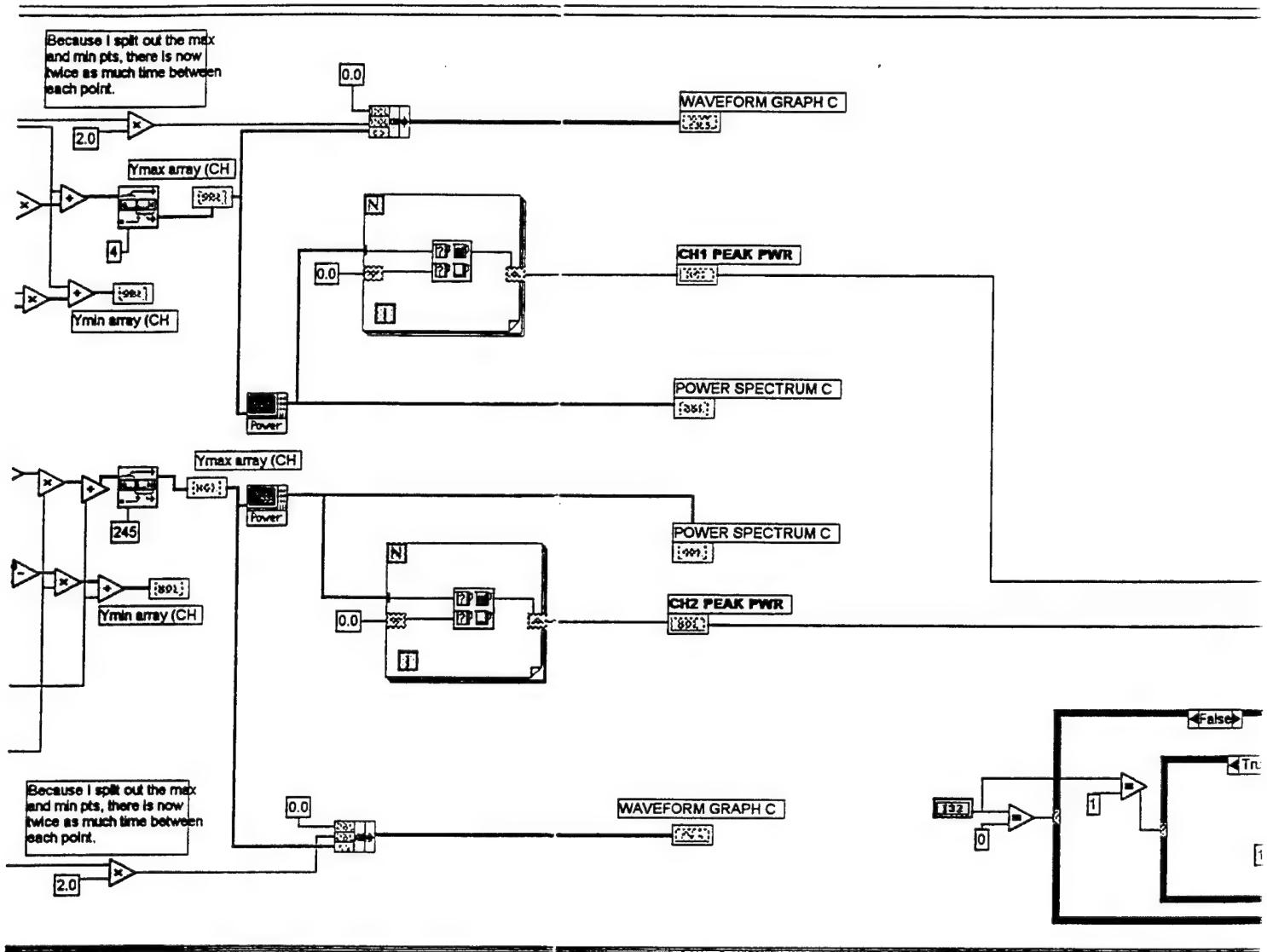


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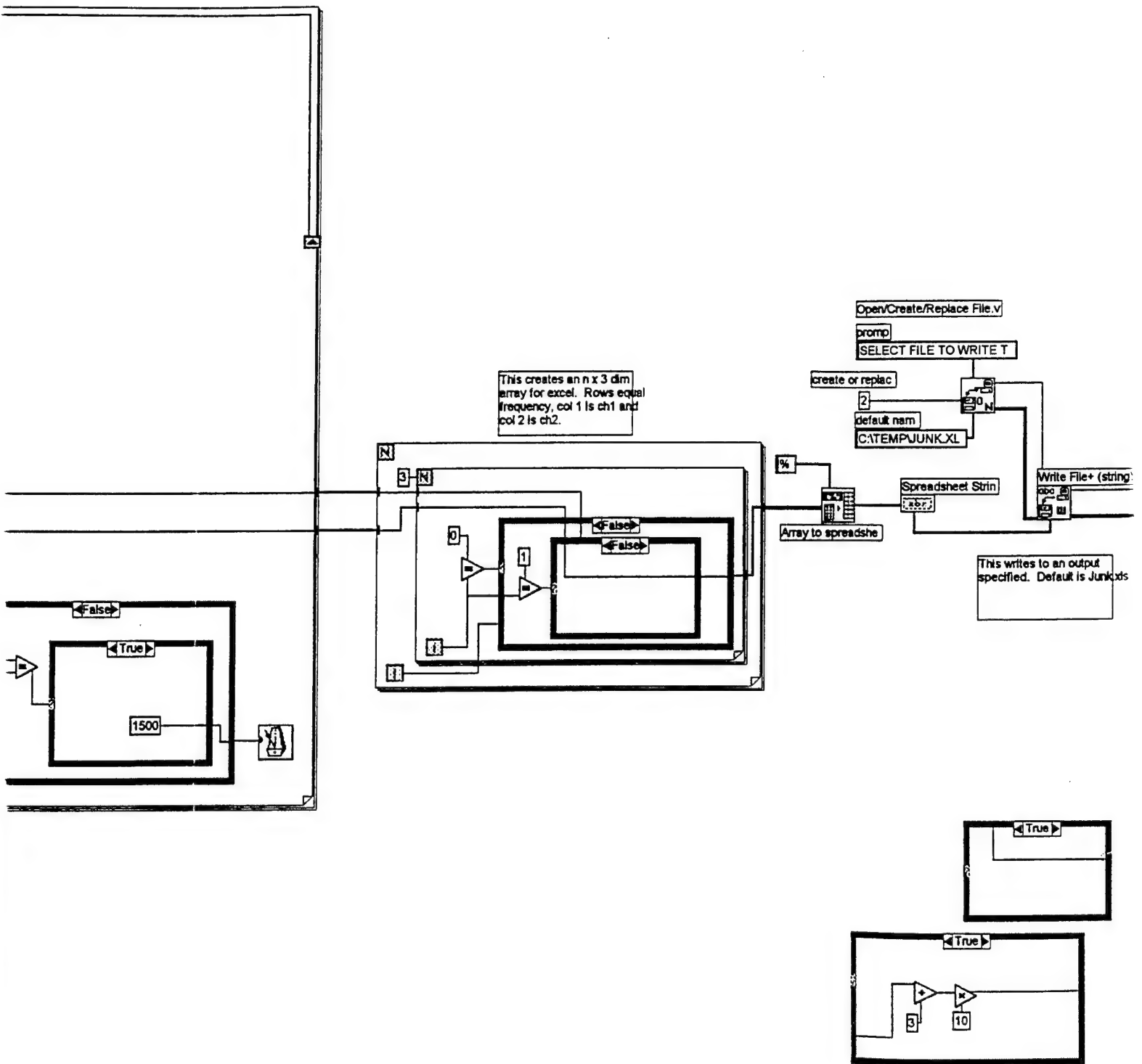


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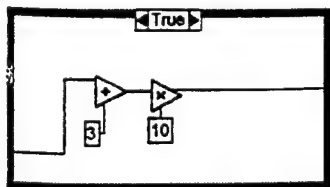
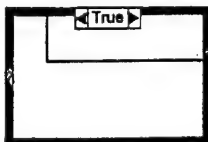
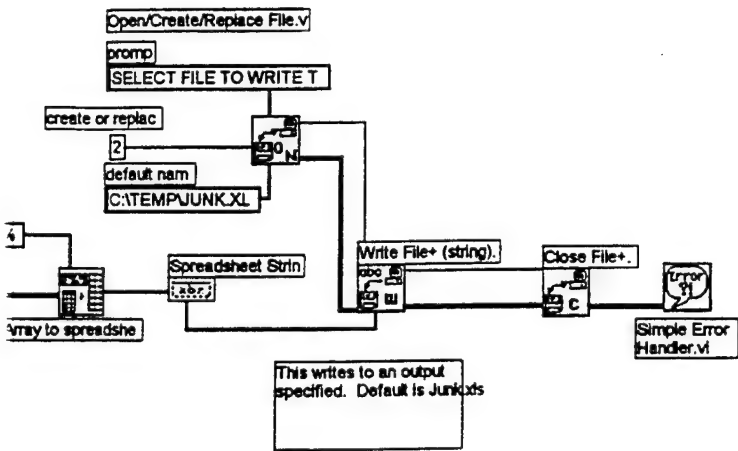
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①



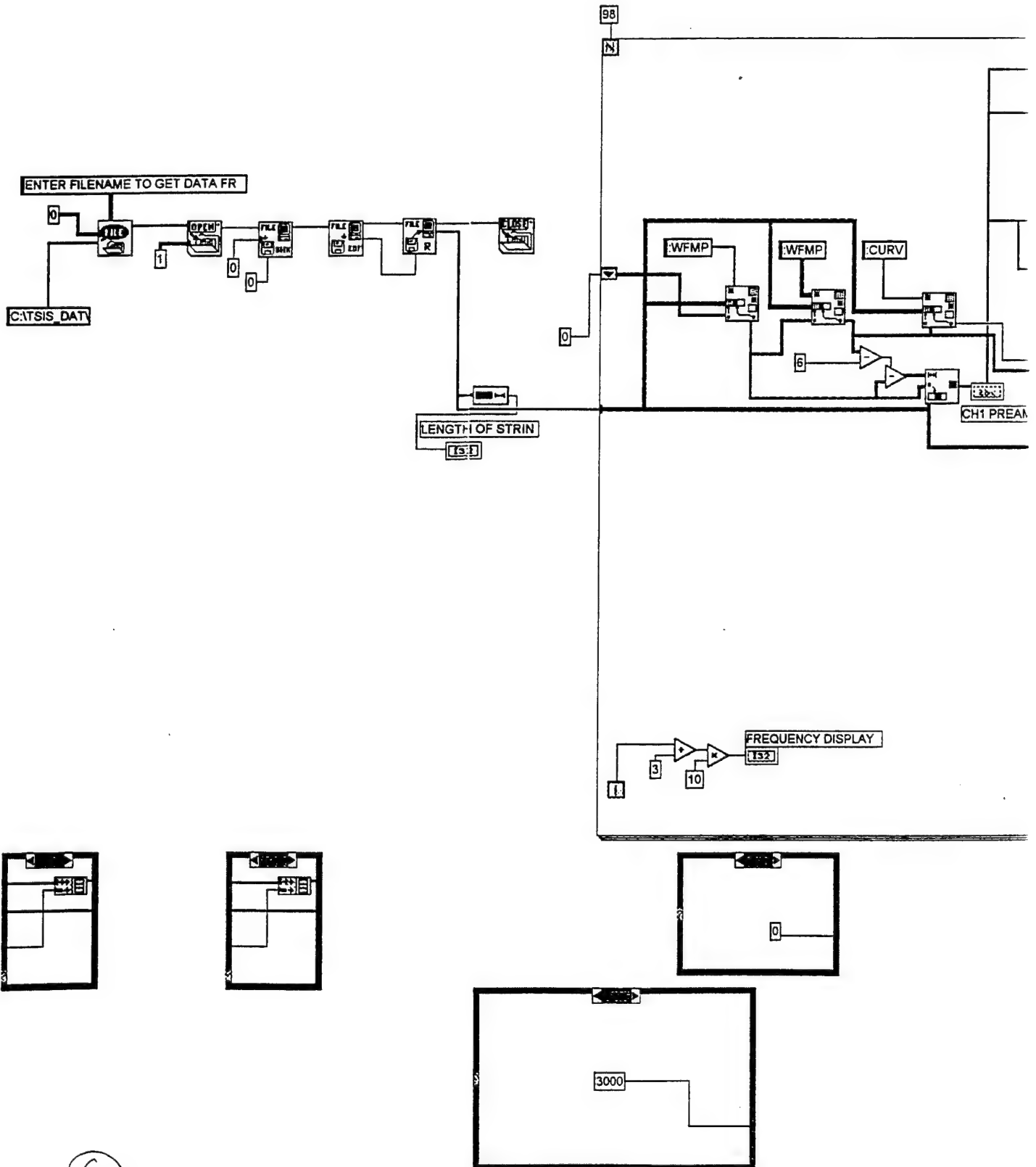
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3

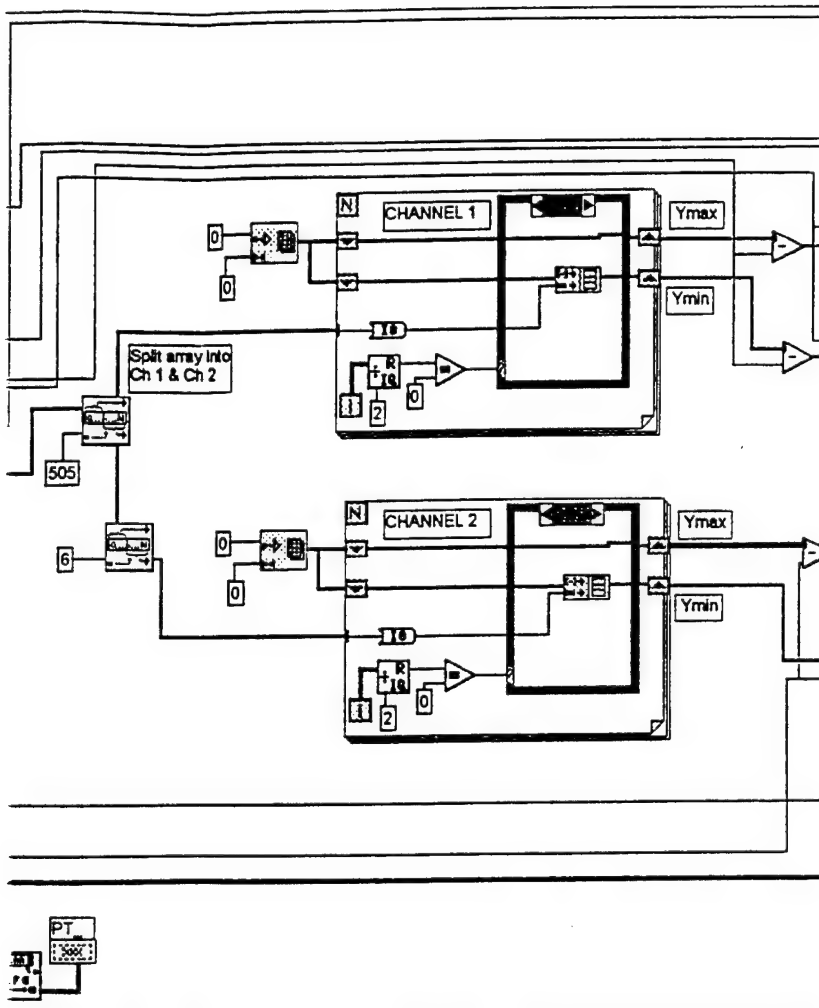
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# Block Diagram





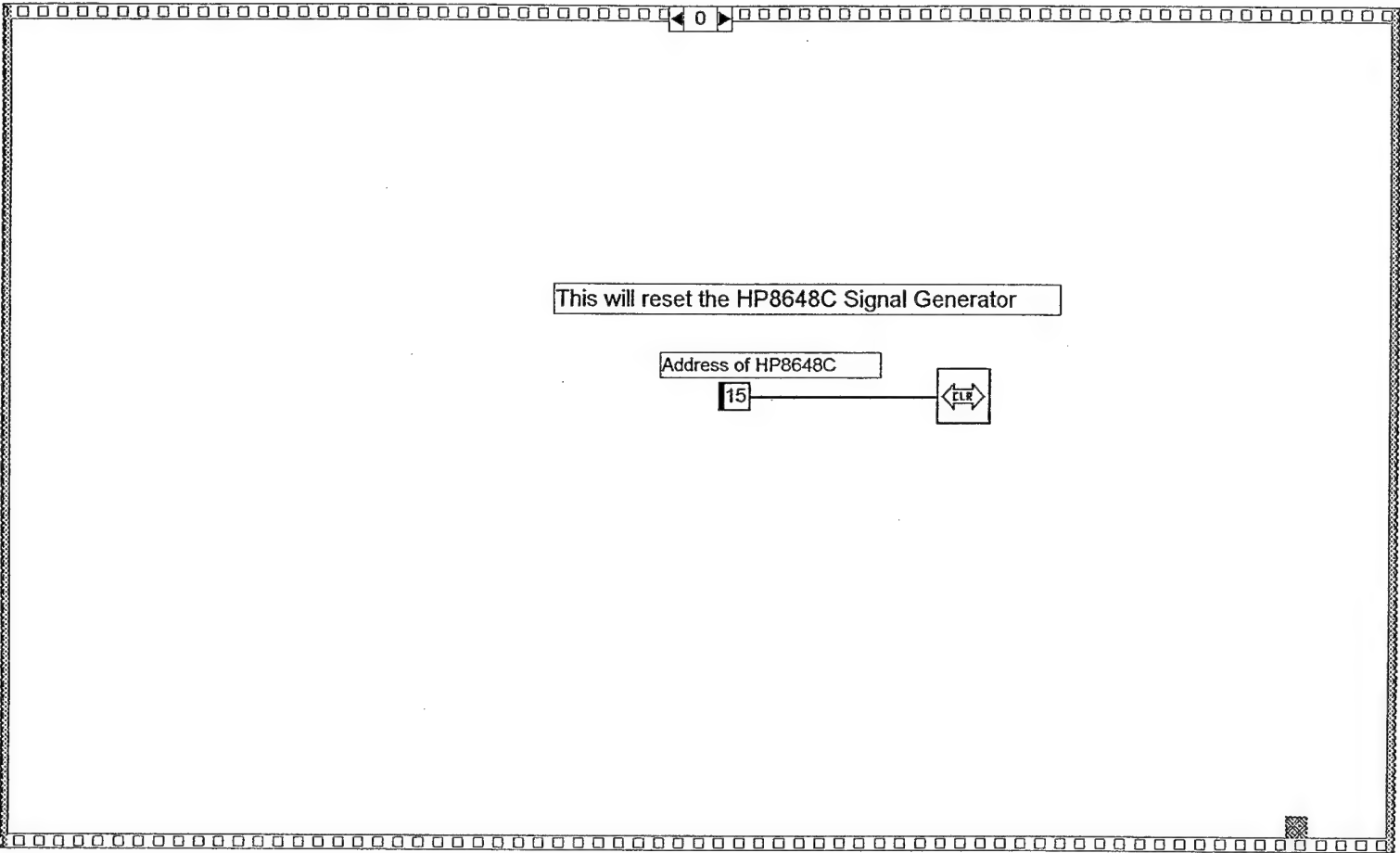
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3

**APPENDIX B**  
**DATA ANALYSIS SOFTWARE**

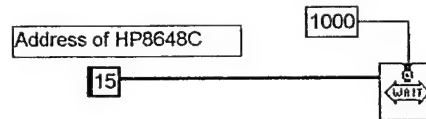
Block Diagram





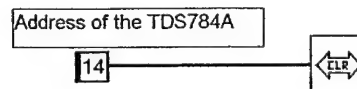
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Wait for the HP8648C Signal Generator to RESET



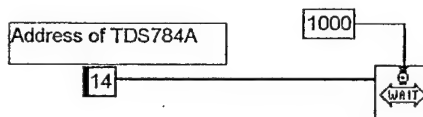
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This will reset the Tektronix TDS784A



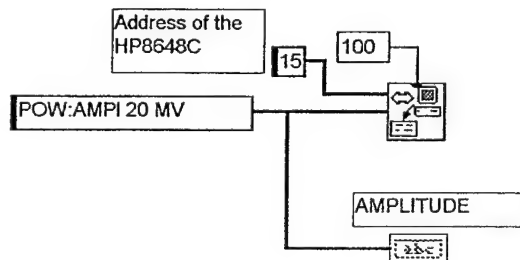
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Wait for the Tektronix TDS784A to RESET



4

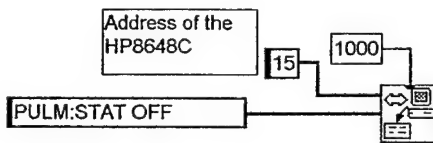
This sets the AMPLITUDE for the HP8648C





◀ 5 ▶

This turns the PULSE MODULATION OFF

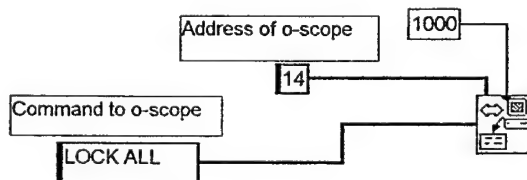


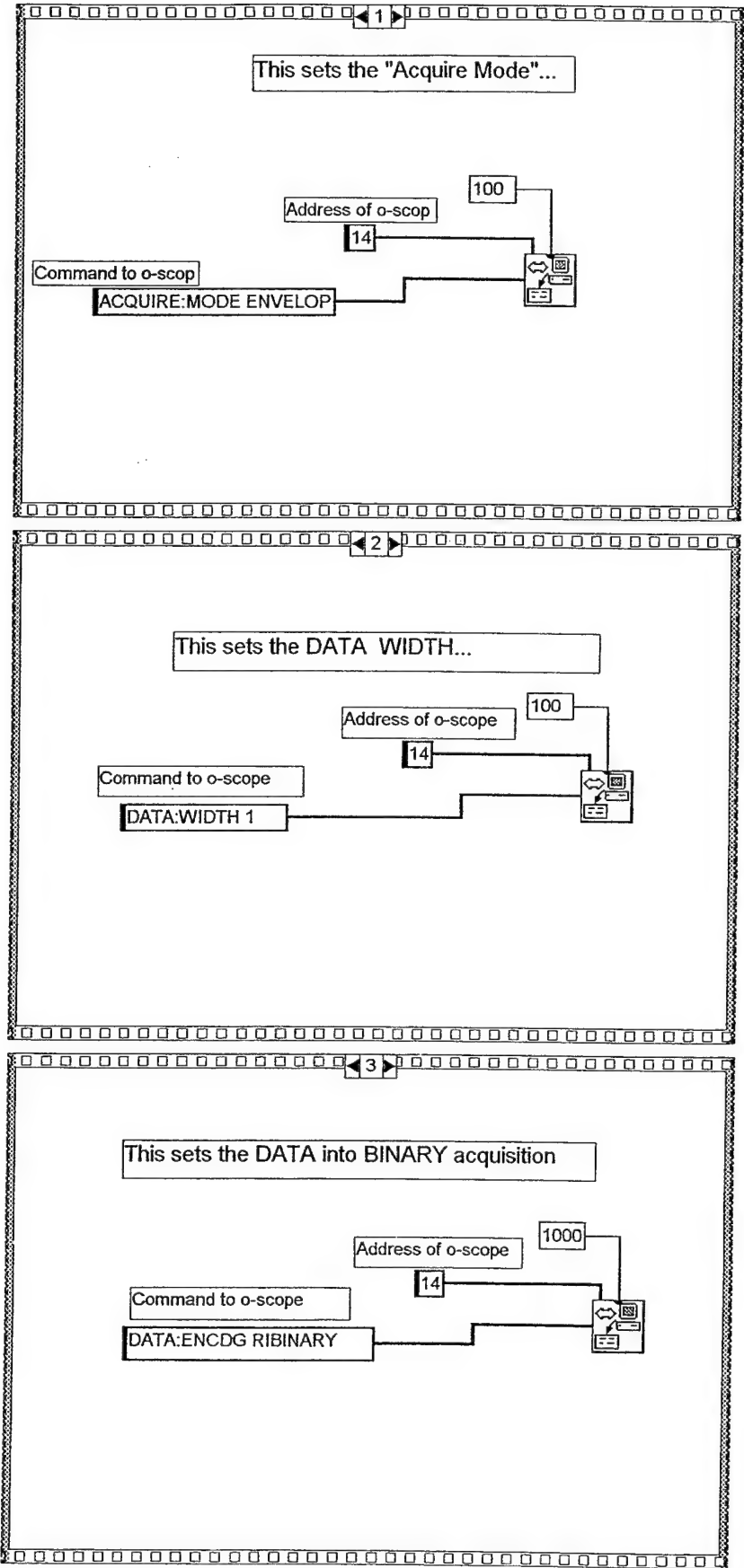
◀ 6 ▶

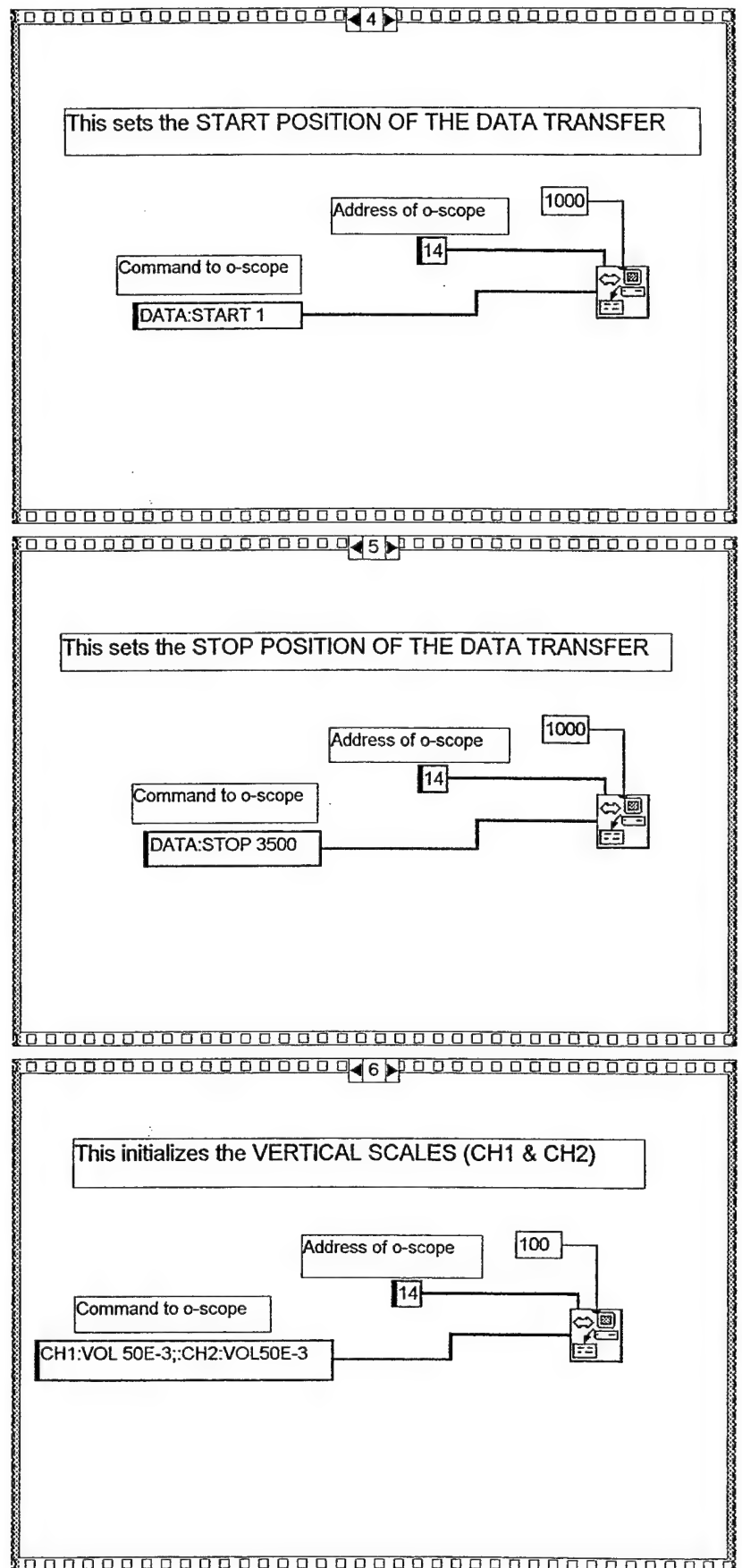
This should set up the MEASUREMENTS for the two (2) CHANNELS.....

◀ 0 ▶

This locks out the o-scope front panel controls....



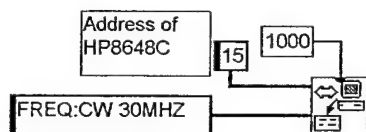






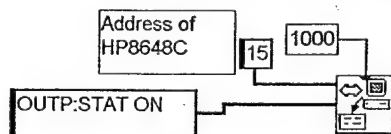
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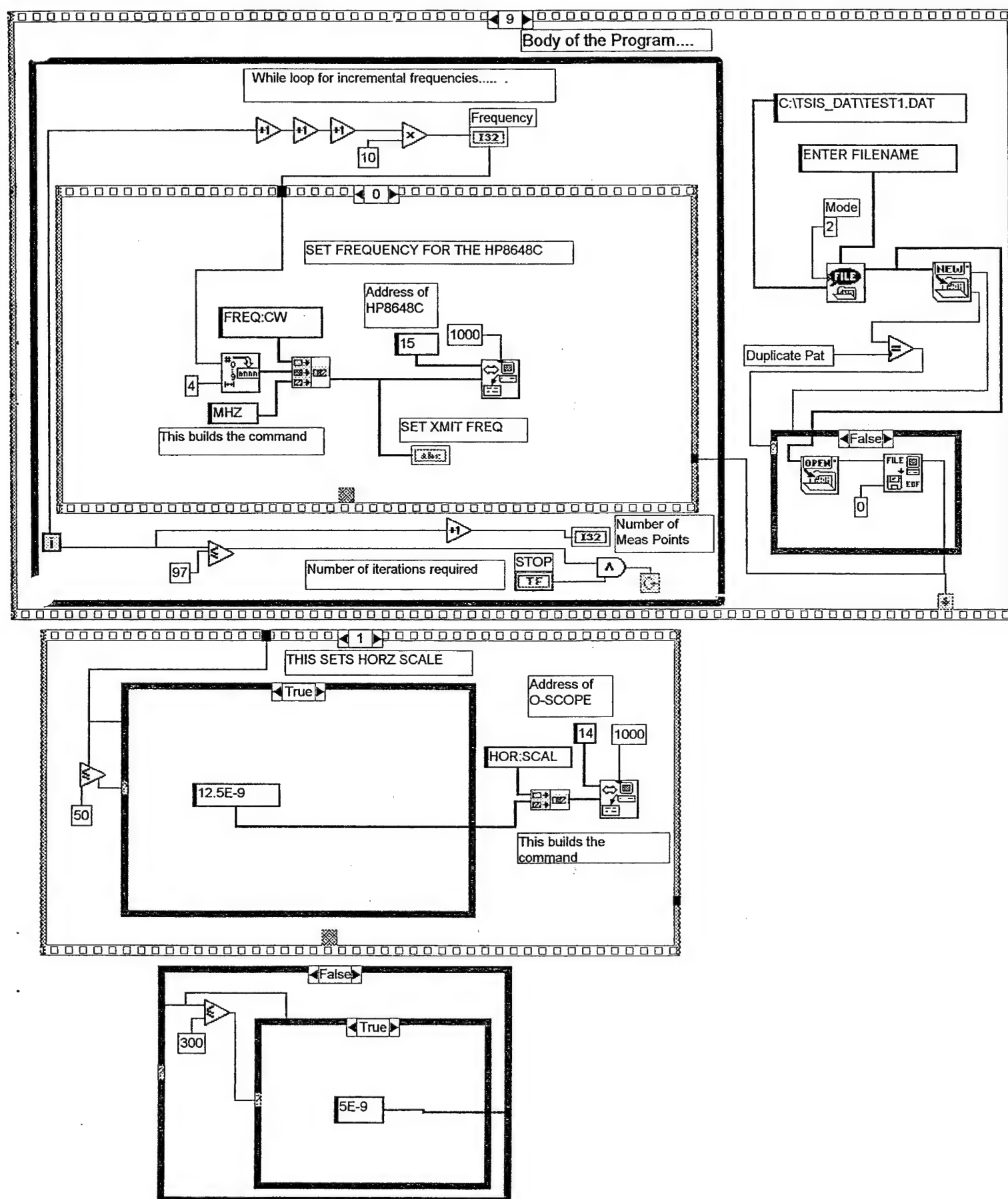
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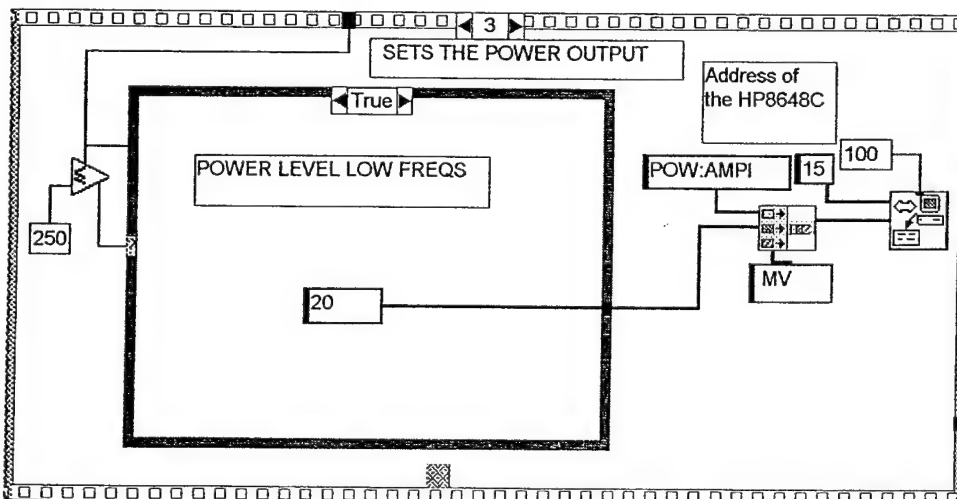
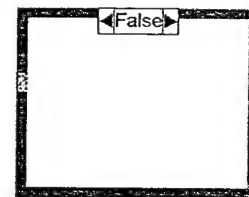
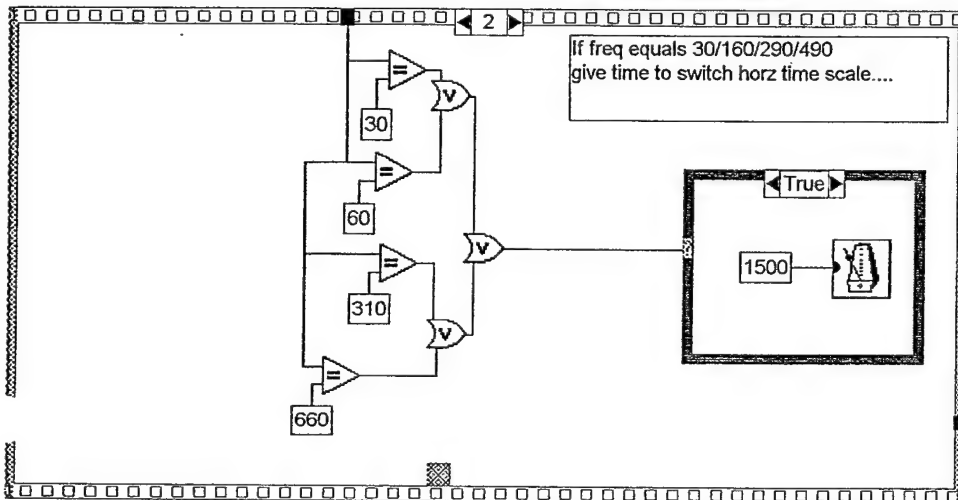
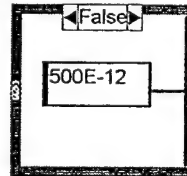
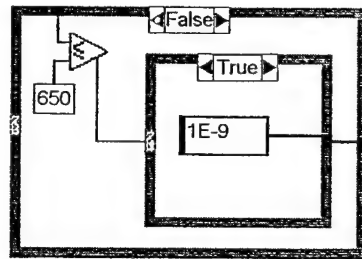


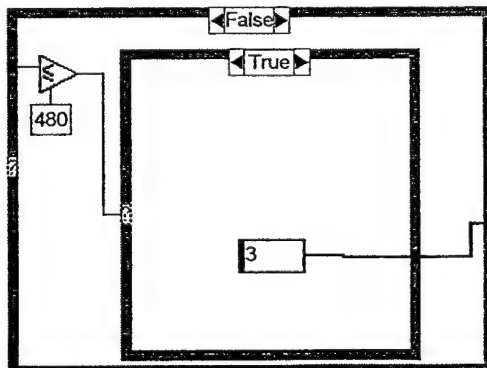
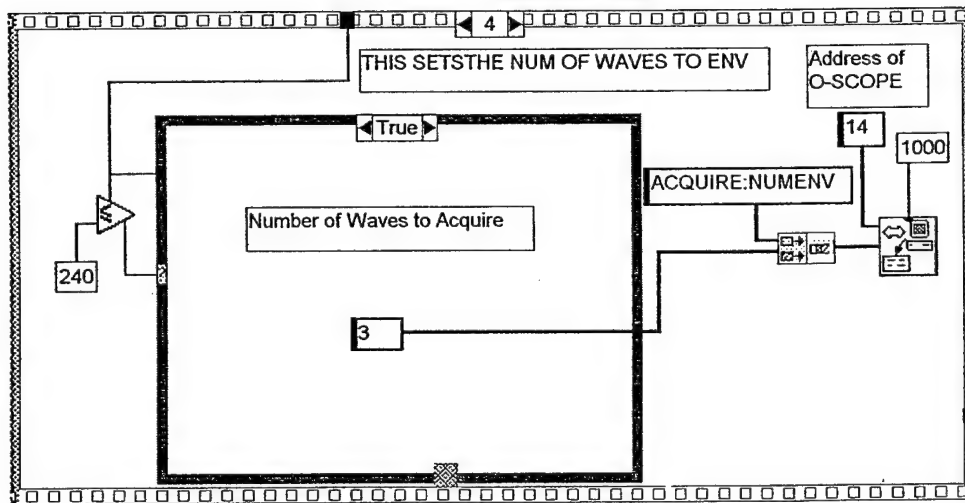
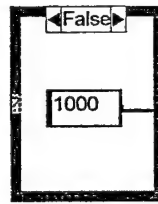
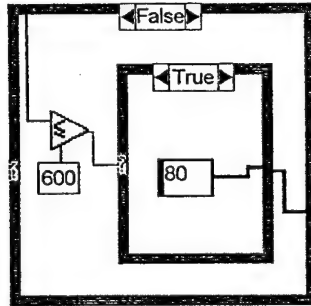
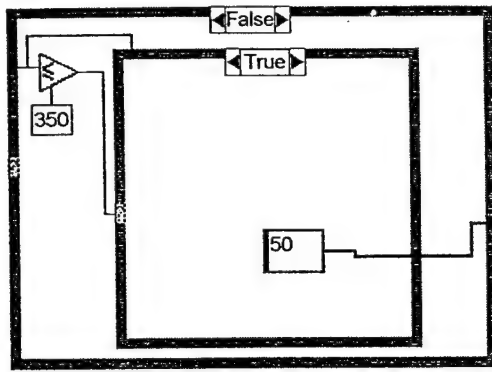
8

\*\*\* TRANSMIT SIGNAL \*\*\*



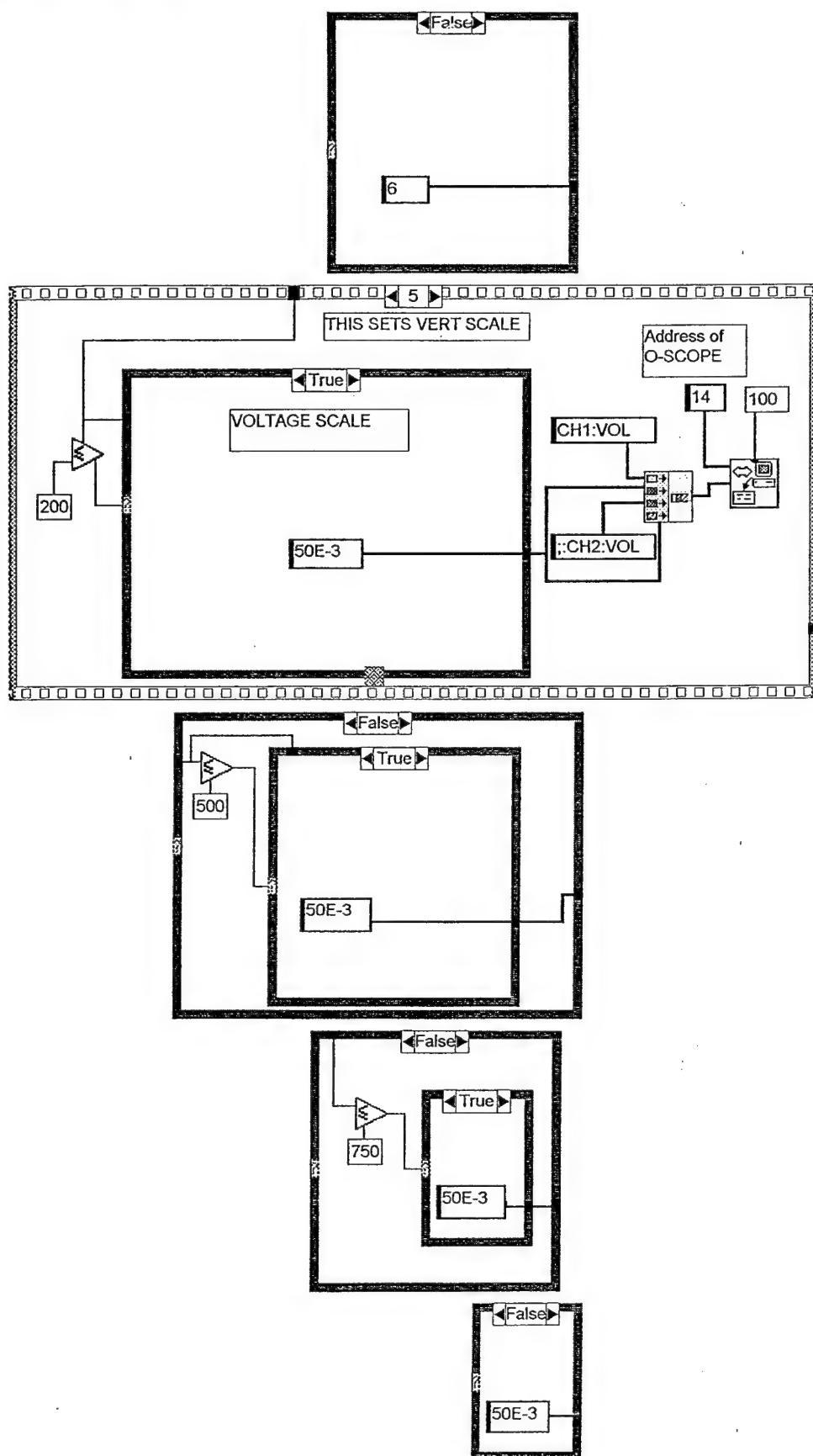








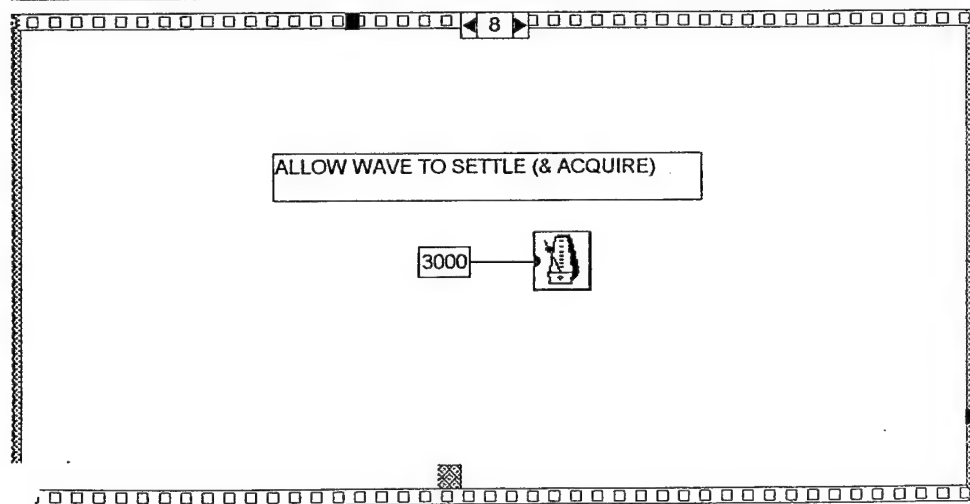
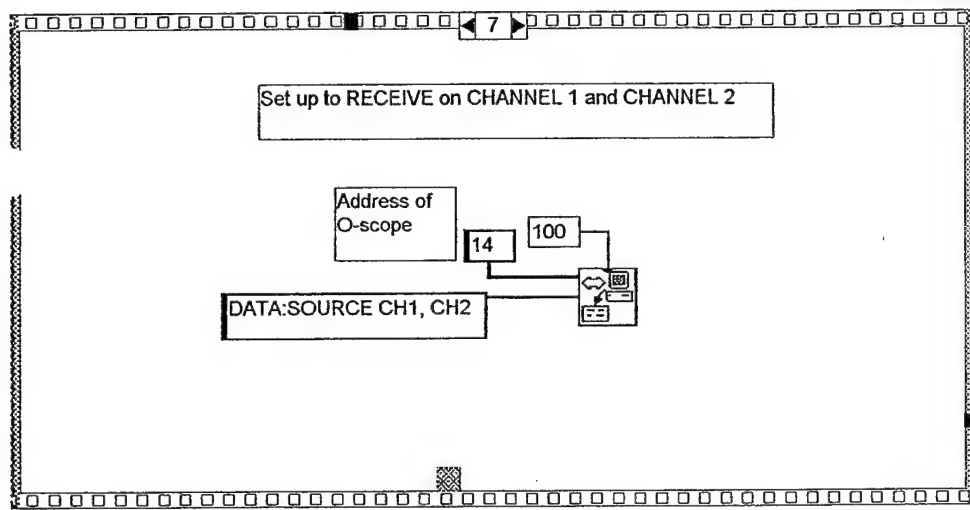
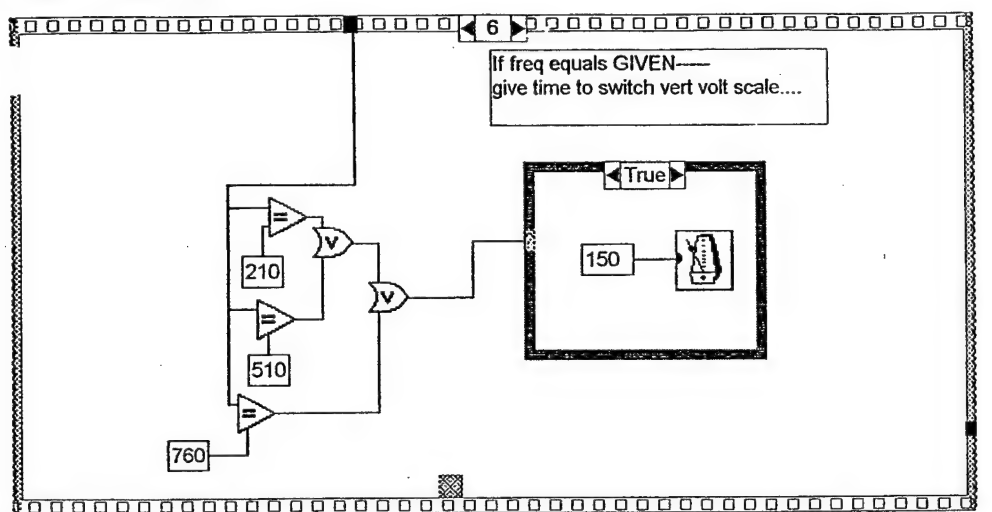
THESIS.VI  
06/12/97 12:33 PM

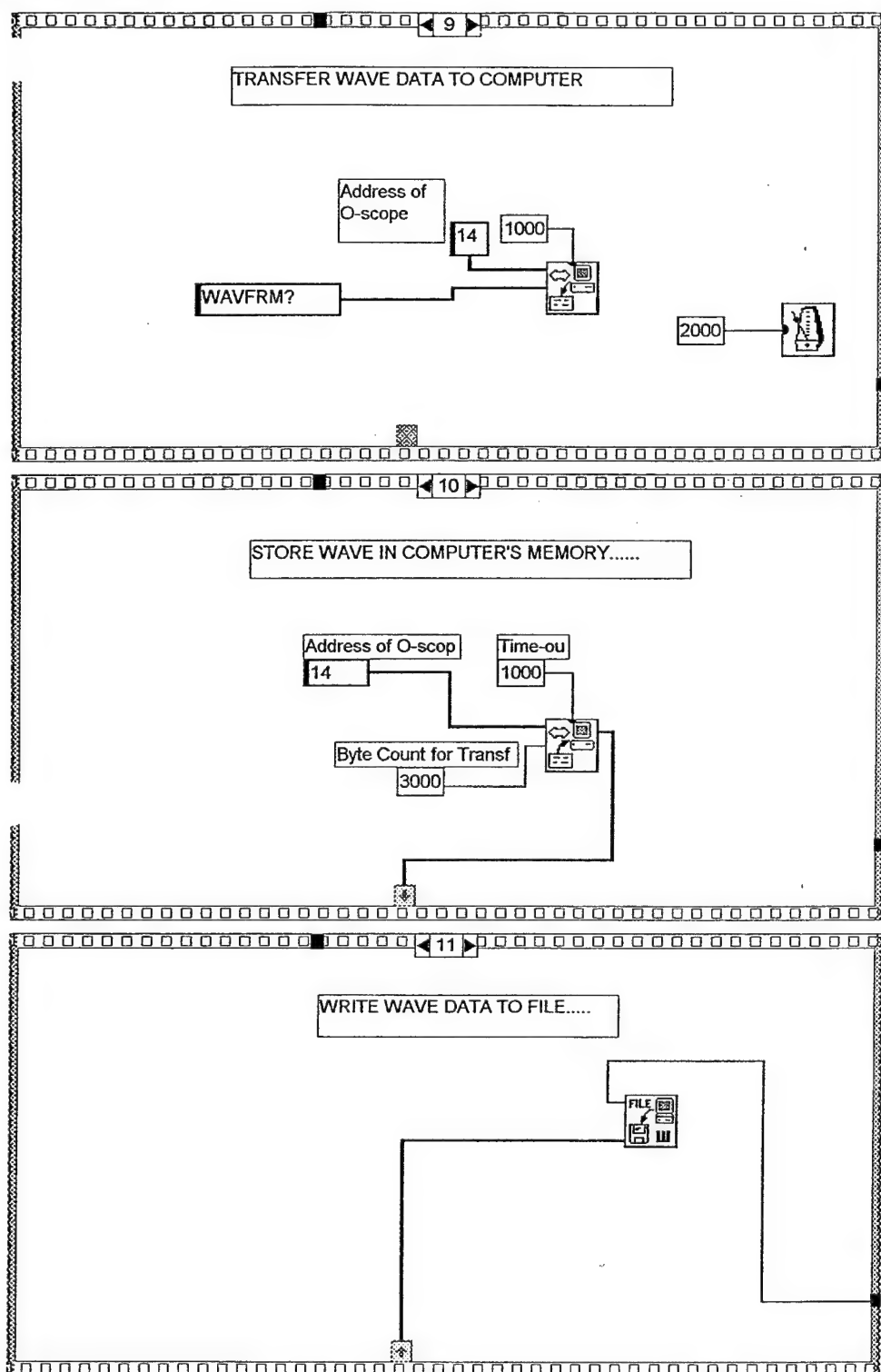


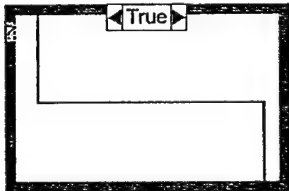


THESIS.VI

06/12/97 12:33 PM









10

CLOSE FILE



11

\*\*\* TRANSMIT SIGNAL \*\*\* OFF

Address  
of  
HP8648C  
15

1000

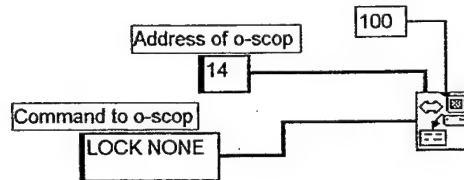
OUTP:STAT OFF





12

This UNlocks the o-scope front panel controls....



**APPENDIX C**  
**EQUIPMENT SPECIFICATIONS**  
**AND CERTIFICATES OF CALIBRATION**

# 607L Specifications

Revision Level: A

Class of Operation	Class A
Frequency Range	0.5 to 1000 MHz instantaneous
Rated RF Power Output	7.0 Watts (+38.4 dBm) minimum at 1 dB gain compression
Saturated RF Power Output	10 Watts minimum at 0dBm RF power input
Harmonic Level	-20 dBc minimum at rated RF power output
Third Order Intercept Point	+51 dBm typical; +48 dBm minimum
Small Signal Gain	45 dB nominal; 47 dB maximum
Small Signal Gain Flatness	$\pm 1.5$ dB typical; $\pm 2$ dB maximum
Noise Figure	11 dB maximum, 1.0 to 1000 MHz 13 dB maximum, 0.5 to 1.0 MHz
Load Impedance for Ratings	50 $\Omega$ / 1.10 VSWR maximum
RF Input Impedance/ VSWR	50 $\Omega$ / 2.5:1 maximum
RF Output Impedance/ VSWR	50 $\Omega$ / 3.0:1 maximum, 150 to 1000 MHz 10.0:1 maximum, 0.5 to 150 MHz
RF Input Overdrive Limit	+13 dBm (1 Vrms) maximum
RF Stability	Unconditional
Spurious Output	-60 dBc minimum
Protection RF Amplifier Module	Fully protected against out-of-band operation, overdrive, output load VSWR and over-temperature

**Primary AC Power Input**

<b>Voltage</b>	100 - 240 VAC; +10%, -15%
<b>Frequency</b>	47-63 Hz
<b>Frequency Option</b>	47-63, 360-440 Hz
<b>Note:</b> 360-440Hz AC power line frequency operation is optional. When operating within the optional AC line frequency range of 360-440Hz, the model 607L is <u>not</u> UL recognized, CSA certified or TUV approved.	
<b>Power</b>	325 VA maximum, single phase
<b>Protection</b> <b>+25VDC Power Supply</b>	Fully protected against over-voltage/ current and temperature
<b>EMI/RFI Compliance</b>	Independently tested to be compliant with electromagnetic compatibility (EMC) requirements as delineated in the applicable specifications (EN55011, IEC 801-2, IEC 801-3, and IEC 801-4) for Self Declaration to the EMC directive 89/336/EEC.
<b>Safety Compliance</b>	Designed to meet CSA, TUV and UL standards.*

**Environmental**

<b>Operating Temperature</b>	5 to 40°C ambient*
<b>Non-operating Temperature</b>	-20 to 85°C ambient
<b>Altitude</b>	up to 6500 feet*
<b>Humidity</b>	up to a maximum relative humidity of 80% for temperatures from 5 to 31°C decreasing linearity to 50% maximum relative humidity at 40°C.*
<b>Cooling System</b>	Forced air; front panel intake, rear panel exhaust
<b>Equipment Pollution Degree</b>	2
<b>Equipment Installation Category</b>	2
<b>Front Panel Controls</b>	AC Power (rocker type switch)
<b>Front Panel LED Indicators</b>	AC ON (green) TEMP (yellow)

Front Panel Connectors	RF Input/Output - type 'N' female
Rear Panel Connectors	AC POWER - IEC 320 (10A) male - AC line cord supplied, International (harmonized) ENI Part Number: 11710
Rear Panel Chassis Ground Stud	M6 (metric) thread
Size (H x W x D)	3.46 x 8.81 x 15.13" nominal (88.0 x 223.8 x 384.2 mm) <i>Dimensions exclusive of handles, connectors and feet</i>
Weight	10.1 lbs (4.6 kg) nominal
Rack-Mounting Option	19" EIA rack-mounting front panel

\* CSA, TUV, UL certifications pending.

**Asset ID#** 765419  
**Model No:** ENI/607L  
**Serial No:** 135  
**Description:** POWER AMPLIFIER  
**Customer:** NAVAL RESEARCH LAB  
**Address:** 4555 OVERLOOK AVE SW RECEIVING OFFICER BLDG 207  
WASHINGTON DC 20375-5329  
**Customer P.O. No:** N00173-97P-1319  
**Agreement No:** 1005782  
**Certificate No:** 10057820

This certifies that the above product was calibrated in compliance with MIL-STD-45662A and ANSI/NC SL Z540-1-1994 using applicable procedures. This certificate cannot be reproduced except in full without written approval of AT&T Capital Corporation, Instrument & Data Services. It pertains only to the asset listed above.

The Quality System of AT&T Capital Corporation conforms to the Quality System Standard ISO 9002, 1994 Certificate Number QSC-3935.

At planned intervals measurement standards are calibrated by comparison to or measurement against national standards, natural physical constants, consensus standards, or by ratio type measurements using self calibrating techniques.

National Standards are administered by NIST (National Institute of Standards and Technology) or other recognized national standards laboratories.

**Testing found this instrument to be in Tolerance.**

Supporting documentation relative to traceability is on file and is available for examination upon request.

The recommended calibration interval is 12 months, and the calibration due date based on this interval is Mar 26, 1997.

**Temperature:** 72

**Relative Humidity:** 22

**Calibration date:** Mar 26, 1996

**Review Date:** Dec 17, 1996

**Calibrated By:** BRYAN ALDAY

**Quality Assurance:**



*Larry L. Pletcher*

**Asset ID#** 765419  
**Model No:** ENI/607L  
**Serial No:** 135  
**Description:** POWER AMPLIFIER  
**Customer:** NAVAL RESEARCH LAB  
**Address:** 4555 OVERLOOK AVE SW RECEIVING OFFICER BLDG 207  
 WASHINGTON DC 20375-5329  
**Customer P.O. No:** N00173-97P-1319  
**Agreement No:** 1005782  
**Certificate No:** 10057820

**Laboratory Standards**

Model Number	Model Description	Asset ID	Cal Type	Cal Date	Cal Due Date
FLU/6080A	SIG GEN	9757	CAL	Oct 27, 1995	Oct 27, 1996
HP/436A	POWER METER	9473	CAL	Jan 11, 1996	Mar 11, 1997
HP/8481B	POWER SENSOR	9438	CAL	Dec 12, 1995	Dec 12, 1996
HP/8753C;A	OPTIONS 006, 010	9782	CAL	Feb 07, 1996	Aug 07, 1996
HP/85047A	S-PARAMETER TEST SET	9843	CAL	Aug 25, 1995	Aug 25, 1996

**Asset ID#** 744868  
**Model No:** HP/8648C;A  
**Serial No:** 3443U00419  
**Description:** W/OPT. 1E5, 1E6  
**Customer:** NAVAL RESEARCH LAB  
**Address:** 4555 OVERLOOK AVE SW RECEIVING OFFICER BLDG 207  
WASHINGTON DC 20375-5329  
**Customer P.O. No:** N00173-97-P0532  
**Agreement No:** 1001398  
**Certificate No:** 10013983

This certifies that the above product was calibrated in compliance with MIL-STD-45662A and ANSI/NCSL Z540-1-1994 using applicable procedures. This certificate cannot be reproduced except in full without written approval of AT&T Capital Corporation, Instrument & Data Services. It pertains only to the asset listed above.

The Quality System of AT&T Capital Corporation conforms to the Quality System Standard ISO 9002, 1994 Certificate Number QSC-3935.

At planned intervals measurement standards are calibrated by comparison to or measurement against national standards, natural physical constants, consensus standards, or by ratio type measurements using self calibrating techniques.

National Standards are administered by NIST (National Institute of Standards and Technology) or other recognized national standards laboratories.

**Testing found this instrument to be in Tolerance.**

Supporting documentation relative to traceability is on file and is available for examination upon request.

The recommended calibration interval is 39 months, and the calibration due date based on this interval is Aug 08, 1999.

**Temperature:** 72 **Relative Humidity:** 54

**Calibration date:** May 08, 1996 **Review Date:** Dec 19, 1996

**Calibrated By:** STEVE MASSEY

**Quality Assurance:** 

**Asset ID#** 744868  
**Model No:** HP/8648C;A  
**Serial No:** 3443U00419  
**Description:** W/OPT. 1E5, 1E6  
**Customer:** NAVAL RESEARCH LAB  
**Address:** 4555 OVERLOOK AVE SW RECEIVING OFFICER BLDG 207  
 WASHINGTON DC 20375-5329  
**Customer P.O. No:** N00173-97-P0532  
**Agreement No:** 1001398  
**Certificate No:** 10013983

**Laboratory Standards**

Model Number	Model Description	Asset ID	Cal Type	Cal Date	Cal Due Date
HP/9133L	DISK DRIVE	9594			
HP/8116A	PULSE/FUNCTION GEN.	9909	CAL	Sep 15, 1995	Sep 15, 1996
HP/8902A	MEASURING RECEIVER	9584	CAL	Dec 29, 1995	May 29, 1996
HP/11792A	MODULE	9723	CAL	Mar 04, 1996	Aug 04, 1996
HP/11793A	MW CONVERTER	9586			
HP/8340B	SYNTHESIZED SWEEPER	9765	CAL	Apr 17, 1996	Jul 17, 1996
HP/8663A	SYNTHESIZER	9952	CAL	Jan 08, 1996	Jan 08, 1997
HP/8566B	SPECTRUM ANALYZER	9838	CAL	Jul 27, 1995	Jul 27, 1996
HP/54100D	DIGITIZING SCOPE	9585	CAL	Mar 18, 1996	Aug 18, 1996
HP/3456A	VOLTMETER	9583	CAL	Jul 11, 1995	Jul 11, 1996
HP/8903B	ANALYZER W/010,051,907	9580	CAL	Apr 30, 1996	Apr 30, 1997



# CERTIFICATE OF CALIBRATION

The instrument listed below has been calibrated in accordance with the requirements of ANSI/NCSL-2540-1994, MIL-STD 45662A, ISO 9002 Section 4.10/4.11, ISO Guide 25, ISO 10012. Standards used are traceable to the National Reference Standards as maintained by the National Institute of Standards and Technology. This instrument meets the manufacturer's published specifications.

Asset Number	: 69135	MFG / Model	: ARA / LPB-2520/A
Serial Number	: 1050		
Calibration Interval :	: 36		
Calibration Date	: Nov 21, 1996	Calibration Due Date	: Nov 21, 1999
Calibration Procedure	: MANUFACTURER'S PROCEDURE		
Temperature	: 70F	Humidity	: 50%
Certificate Number	: 951018596		
Agreement Number	: 196418-10	Customer Name	: NAVAL RESEARCH
Name of calibrating organization	: A.R.A.	Received Condition	: IN TOLERANCE

PO#N00173-97P0527

## Calibration Equipment Used:

STD#	Mfg	Model	Description	Cal-Due Dat
------	-----	-------	-------------	-------------

Relative supporting documentation to traceability is on file and is available upon request.  
Without consent, this certificate shall not be reproduced except in full, without prior written approval from Telogy. All results of this calibration relate only to the items that were calibrated.  
In the event this certificate contains the calibration results of a subcontractor, those results will be clearly identified within this certification.

  
Certifying Authority

**CERTIFICATE OF CONFORMANCE**

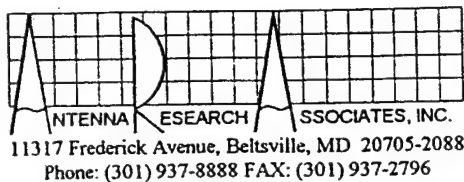
A verification has been performed on the instrument below.  
This instrument meets the manufacturer's published  
performance specifications.

Manufacturer / Model Number	: ARA TP-5
Asset Number	: 66860
Serial Number	: NSN
Verification Date	: Nov 19, 1996
Procedure used	: MANUFACTURER'S PROCEDURE
Temperature	: 70F
Humidity	: 50%
Certificate Number	: 951018595
Customer Name	: NAVAL RESEARCH
Agreement Number	: 196418-10
Technician number	: 28/93

PO#N00173-97P0527

I further certify that the supplies or services are of  
the quality specified and conform in all respects with  
the contract requirement, including preservation,  
packaging, and physical item identification (part number),  
and are in the quantity shown on the accompanying TELOGY  
agreement referenced above.

  
Certifying Authority  
Telogy Incorporated



## Certificate Of Calibration

Per MIL-STD-45662A

Model Number :	LPB-2520/A	Temperature :	55°F
Serial Number :	1076	Humidity :	56%
Calibration Due :	11/19/97	Job Number :	87-110
Purchase Order :	71814RAH		

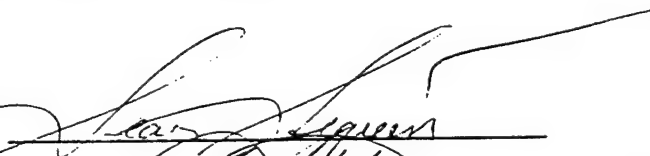

Report Number(s) : 3551A01945

Test Equipment Used : hp8560E Spectrum Analyzer

Out of Tolerance conditions : None

Calibrated By :

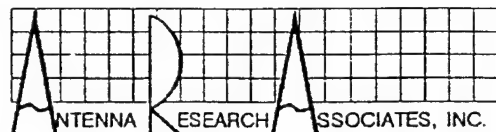
Certified By :

  
  
Authorized Signature

21 NOV 96  
Date

Calibrations of reference standards and instrumentation that have been used in obtaining results, are traceable to the National Institute of Standards and Technology, or other nationally accepted measuring systems. Instruments and standards are periodically calibrated and maintained in accordance to the calibration system requirements of MIL-STD-45662A.

05/31/94



11317 Frederick Avenue, Beltsville, MD 20705

# E-FIELD ANTENNA FACTOR CALIBRATION

$$E(\text{dB V/m}) = V_o(\text{dB V}) + AFE(\text{dB/m})$$

Model Number: LPB-2520/A

Frequency MHz	AFE dB 1/m	Gain dBi	Frequency MHz	AFE dB 1/m	Gain dBi
25	20.4	-22.2	190	9.4	6.4
30	17.6	-17.8	195	9.5	6.5
35	16.7	-15.6	200	9.6	6.7
40	16.1	-13.8	210	10.9	5.8
45	14.9	-11.6	220	11.6	5.5
50	14.0	-9.8	230	11.8	5.6
55	11.8	-6.8	240	12.6	5.2
60	10.1	-4.3	250	12.0	6.2
65	7.7	-1.2	300	13.7	6.1
70	6.6	0.5	350	13.1	8.0
75	6.9	0.8	400	14.5	7.8
80	8.0	0.3	450	15.3	8.0
85	8.7	0.1	500	16.1	8.1
90	9.1	0.2	550	17.3	7.7
95	9.4	0.4	600	18.6	7.2
100	9.4	0.8	650	19.0	7.5
105	9.8	0.8	700	19.1	8.0
110	10.5	0.5	750	20.5	7.2
115	10.7	0.7	800	20.5	7.8
120	11.1	0.7	850	20.3	8.5
125	10.9	1.3	900	21.2	8.1
130	10.4	2.1	950	21.6	8.2
135	9.8	3.0	1000	21.8	8.4
140	8.7	4.4	1100	22.4	8.6
145	8.1	5.4	1200	23.2	8.6
150	8.4	5.3	1300	23.5	9.0
155	8.5	5.5	1400	23.9	9.3
160	8.5	5.8	1500	24.7	9.0
165	9.9	4.7	1600	24.9	9.4
170	9.9	4.9	1700	26.0	8.8
175	9.7	5.4	1800	26.2	9.1
180	9.1	6.2	1900	27.2	8.6
185	9.2	6.4	2000	28.1	8.1


Serial number : 1050

Job number : 87-110

Temp & humidity : 55° F, 56%

Date : November 19, 1996

Remarks : 3 meter calibration, Horizontal Polarization.

  
Calibrated By




**11317 Frederick Avenue, Beltsville, MD 20705**

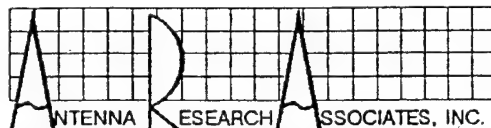
# Certificate Of Conformance

Antenna Research Associates, Inc. hereby certifies that all articles, materials, products, equipment, and services furnished have been produced, assembled, tested and/or inspected in accordance with applicable specifications, drawings, and other purchase order requirements in **Telogy purchase order #71814RAH**.

Item Number: 001  
Model Number: LPB-2520/A  
Serial Number: 1076  
Job Number: 87-110  
Date: November 19, 1996

  
Authorized Signature

01/23/95



11317 Frederick Avenue, Beltsville, MD 20705

### E-FIELD ANTENNA FACTOR CALIBRATION

$$E(\text{dB V/m}) = V_o(\text{dB V}) + \text{AFE}(\text{dB/m})$$

Model Number: LPB-2520/A

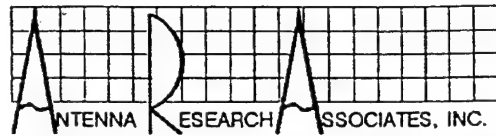
Frequency MHz	AFE dB 1/m	Gain dBi	Frequency MHz	AFE dB 1/m	Gain dBi
25	18.6	-20.4	190	9.9	5.9
30	17.3	-17.5	195	9.8	6.2
35	16.7	-15.6	200	9.8	6.5
40	16.3	-14.0	210	10.4	6.3
45	15.2	-11.9	220	10.9	6.2
50	14.5	-10.3	230	11.8	5.6
55	12.6	-7.6	240	12.6	5.2
60	11.1	-5.3	250	12.1	6.1
65	9.2	-2.7	300	12.9	6.9
70	7.7	-0.6	350	13.6	7.5
75	7.4	0.3	400	14.4	7.9
80	8.5	-0.2	450	15.1	8.2
85	9.1	-0.3	500	16.1	8.1
90	9.4	-0.1	550	17.3	7.7
95	9.6	0.2	600	18.4	7.4
100	9.7	0.5	650	19.0	7.5
105	9.8	0.8	700	19.1	8.0
110	10.0	1.0	750	20.4	7.3
115	10.6	0.8	800	20.5	7.8
120	11.2	0.6	850	20.3	8.5
125	11.6	0.6	900	21.2	8.1
130	11.6	0.9	950	21.6	8.2
135	11.4	1.4	1000	22.0	8.2
140	10.2	2.9	1100	22.2	8.8
145	8.8	4.7	1200	23.0	8.8
150	8.2	5.5	1300	23.5	9.0
155	8.0	6.0	1400	23.9	9.3
160	8.1	6.2	1500	25.2	8.5
165	7.7	6.9	1600	24.9	9.4
170	9.3	5.5	1700	26.0	8.8
175	9.4	5.7	1800	26.4	8.9
180	9.1	6.2	1900	27.6	8.2
185	9.7	5.9	2000	27.7	8.5

Serial number : 1076  
Temp & humidity : 55° F, 56%

Job number : 87-110  
Date : November 19, 1996

Remarks : 3 meter calibration, Horizontal Polarization.

Calibrated By



11317 Frederick Avenue, Beltsville, MD 20705

## Certificate Of Conformance

Antenna Research Associates, Inc. hereby certifies that all articles, materials, products, equipment, and services furnished have been produced, assembled, tested and/or inspected in accordance with applicable specifications, drawings, and other purchase order requirements in **Telogy purchase order #71814RAH**.

Item Number: 001  
Model Number: LPB-2520/A  
Serial Number: 1050  
Job Number: 87-110  
Date: November 19, 1996

  
Authorized Signature



11317 Frederick Avenue, Beltsville, MD 20705-2088  
Phone: (301) 937-8888 FAX: (301) 937-2796

## Certificate Of Calibration

Per MIL-STD-45662A

Model Number :	LPB-2520/A	Temperature :	75°F
Serial Number :	1058	Humidity :	65%
Calibration Due :	08/15/97	Job Number :	97-009
Purchase Order :	71583RAH		

Report Number(s) : 673761-4.

Test Equipment Number(s) : TE-1001, TE-1002, TE-1003, TE-1004.

Out of Tolerance conditions : None

Calibrated By :

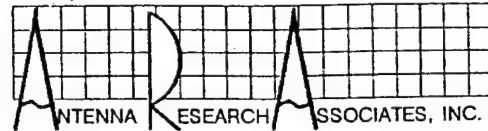
Certified By :

8-16-96

Date

Calibrations of reference standards and instrumentation that have been used in obtaining results, are traceable to the National Institute of Standards and Technology, or other nationally accepted measuring systems. Instruments and standards are periodically calibrated and maintained in accordance to the calibration system requirements of MIL-STD-45662A.

05/31/94

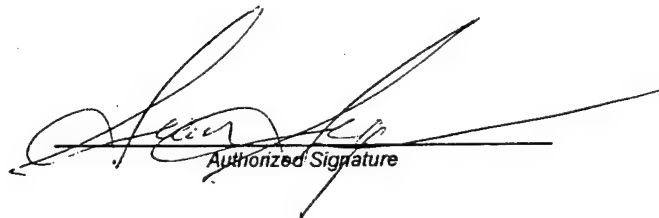


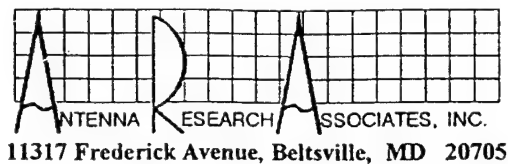
11317 Frederick Avenue, Beltsville, MD 20705

## Certificate Of Conformance

Antenna Research Associates, Inc. hereby certifies that all articles, materials, products, equipment, and services furnished have been produced, assembled, tested and/or inspected in accordance with applicable specifications, drawings, and other purchase order requirements in pursuant **Telogy purchase order #71583RAH.**

Item Number: 001  
Model Number: LPB-2520/A  
Serial Number: 1058  
Job Number: 97-009  
Date: August 15, 1996

  
Authorized Signature



# E-FIELD ANTENNA FACTOR CALIBRATION

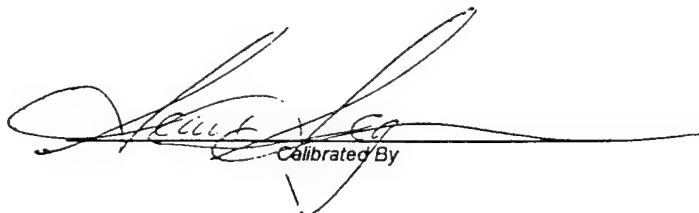
$$E(\text{dB V/m}) = V_o(\text{dB V}) + AFE(\text{dB/m})$$

Model Number: LPB-2520/A

Frequency MHz	AFE dB/m	Gain dBi
25	20.1	-21.9
30	18.1	-18.4
35	17.3	-16.2
40	16.8	-14.6
45	15.1	-11.8
50	14.3	-10.1
60	10.2	-4.4
70	7.1	0.0
80	8.3	0.0
90	9.5	-0.2
100	10.5	-0.3
120	11.8	0.0
140	9.5	3.6
160	8.7	5.6
180	9.4	5.9
200	10.1	6.1
250	12.6	5.6
300	14.4	5.3
400	15.3	7.0
500	17.1	7.1
600	19.1	6.7
700	20.2	6.9
800	20.8	7.5
900	22.2	7.1
1000	23.0	7.2
1500	26.5	7.3
2000	28.8	7.4

Serial number : 1058  
Temp & humidity : 75° F, 65%  
Remarks : 3 meter calibration

Job number : 97-009  
Date : August 15, 1996

  
Calibrated By

# LOG PERIODIC / BICONICAL ANTENNA

MODEL LPB-2520

25 - 2000 MHz

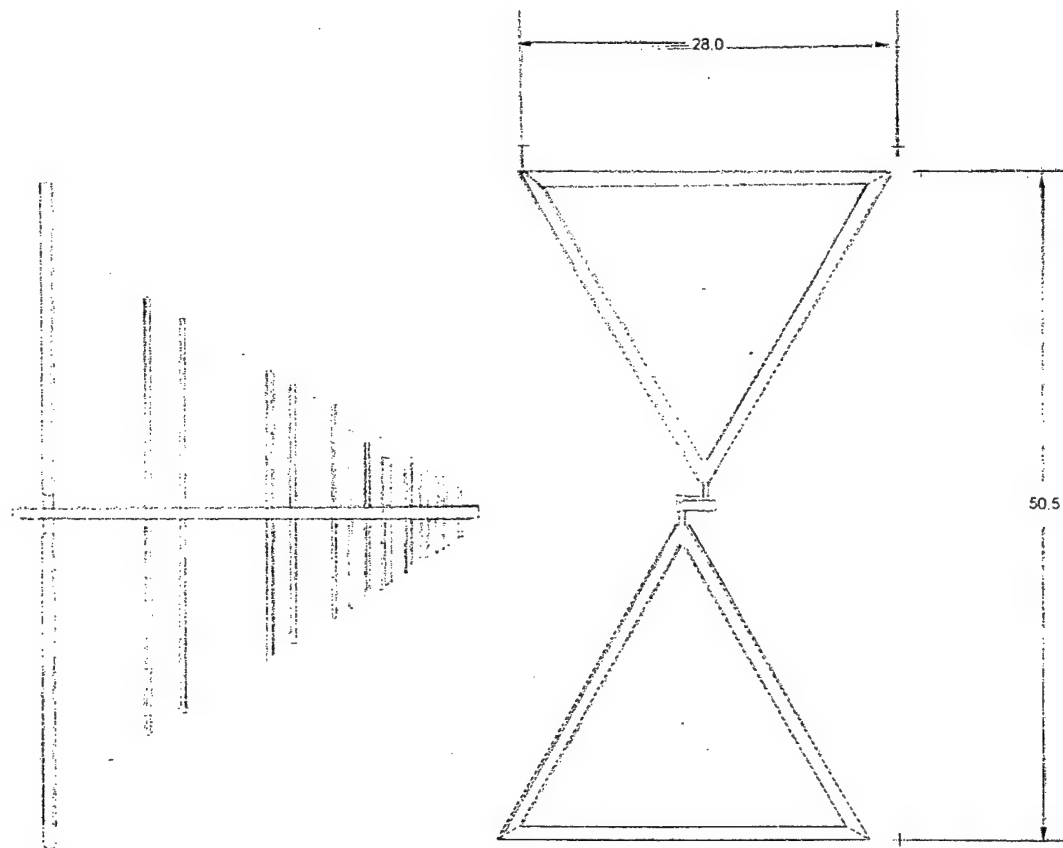


11317 Frederick Avenue, Beltsville, MD 20705-2088  
Phone: (301) 937-8888 FAX: (301) 937-2796

ISSUE: 1  
DATE: 11/95  
PRICE: \$15.00  
TM - 41222

Engineering  
Approval: \_\_\_\_\_

Date: \_\_\_\_\_



MODEL LPB-2520



## LPB-2520 SPECIFICATIONS

### Electrical

Frequency Range:	25 -- 2000 MHz
Impedance:	50 ohms, nominal
Polarization:	Linear
VSWR:	2 : 1 average
Power:	1000 watts cw
Connector:	Type N female

### Mechanical

Length:	38"
Width:	28"
Height:	50.5"
Weight:	10 lbs.



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Phone: (301) 937-8888 FAX: (301) 937-2796

## Certificate Of Calibration

Per MIL-STD-45662A

Model Number :	LPB-2520/A	Temperature :	70°F
Serial Number :	1057	Humidity :	58%
Calibration Due :	06/26/97	Job Number :	97-009
Purchase Order :	71583RAH		


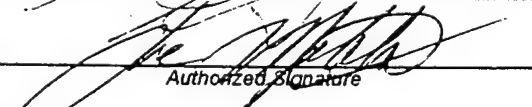
Report Number(s) : 673761-4.

Test Equipment Number(s) : TE-36A & B, TE-77, TE-94, TE-1001,  
TE-1002, TE-1003, TE-1004.

Out of Tolerance conditions : None

Calibrated By :

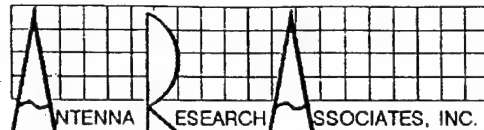
Certified By :

  
  
Authorized Signature

27 JUN 96  
Date

Calibrations of reference standards and instrumentation that have been used in obtaining results, are traceable to the National Institute of Standards and Technology, or other nationally accepted measuring systems. Instruments and standards are periodically calibrated and maintained in accordance to the calibration system requirements of MIL-STD-45662A.

05/31/94



11317 Frederick Avenue, Beltsville, MD 20705

### E-FIELD ANTENNA FACTOR CALIBRATION

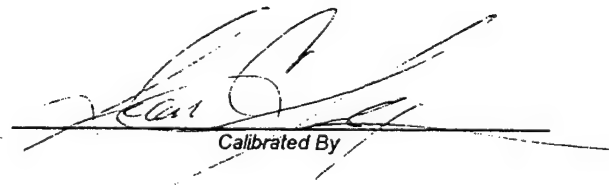
$$E(\text{dB V/m}) = V_o(\text{dB V}) + AFE(\text{dB/m})$$

Model Number: LPB-2520/A

Frequency MHz	AFE dB/m	Gain dBi
25	19.7	-21.5
30	19.9	-20.1
35	17.5	-16.4
40	16.6	-14.3
45	14.5	-11.2
50	12.8	-8.6
60	8.7	-2.9
70	6.3	0.8
80	7.7	0.6
90	9.4	-0.1
100	10.5	-0.3
120	11.3	0.5
140	9.1	4.1
160	8.5	5.8
180	9.2	6.1
200	9.7	6.5
250	12.0	6.2
300	13.9	5.9
400	14.8	7.5
500	16.3	7.9
600	19.0	6.8
700	19.2	7.9
800	19.9	8.4
900	21.5	7.8
1000	21.6	8.6
1500	25.9	7.8
2000	29.7	6.6

Serial number : 1057  
Temp & humidity : 70° F, 58%  
Remarks : 3 meter calibration

Job number : 97-009  
Date : June 26, 1996

  
Calibrated By

R



# CERTIFICATE OF CALIBRATION

The instrument listed below has been calibrated in accordance with the requirements of ANSI/NCSL-Z540-1994, MIL-STD 45662A, ISO 9002 Section 4.10/4.11, ISO Guide 25, ISO 10012. Standards used are traceable to the National Reference Standards as maintained by the National Institute of Standards and Technology. This instrument meets the manufacturer's published specifications.

Asset Number	: 66407	MFG / Model	: ARA / LPB-2520/A
Serial Number	: 1057		
Calibration Interval :	: 36		
Calibration Date	: Jun 25, 1996	Calibration Due Date :	Jun 25, 1999
Calibration Procedure	: MANUFACTURER'S PROCEDURE		
Temperature	: 70F	Humidity	: 50%
Certificate Number	: 951018519		
Agreement Number	: 196418	Customer Name	: NAVAL RESEARCH
Name of calibrating organization :	A.R.A.	Received Condition	: IN TOLERANCE

PO#N00173-97P0527

## Calibration Equipment Used:

STD#	Mfg	Model	Description	Cal-Due Dat
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Relative supporting documentation to traceability is on file and is available upon request.

Without consent, this certificate shall not be reproduced except in full, without prior written approval from Tology. All results of this calibration relate only to the items that were calibrated.

In the event this certificate contains the calibration results of a subcontractor, those results will be clearly identified within this certification.

  
Certifying Authority

## CERTIFICATE OF CALIBRATION

The instrument listed below has been calibrated in accordance with the requirements of ANSI/NCCL-2540-1994, MIL-STD 45662A, ISO 9002 Section 4.10/4.11, ISO Guide 25, ISO 10012. Standards used are traceable to the National Reference Standards as maintained by the National Institute of Standards and Technology. This instrument meets the manufacturer's published specifications.

Asset Number	: 66859	MFG / Model	: ARA / LPB-2520/A
Serial Number	: 1058		
Calibration Interval :	: 36		
Calibration Date	: Aug 16, 1996	Calibration Due Date :	: Aug 16, 1999
Calibration Procedure	: MANUFACTURER'S PROCEDURE		
Temperature	: 70F	Humidity	: 50%
Certificate Number	: 951018520		
Agreement Number	: 196418	Customer Name	: NAVAL RESEARCH
Name of calibrating organization :	: A.R.A.	Received Condition	: IN TOLERANCE

PO#N00173-97P0527

## Calibration Equipment Used:

STD#	Mfg	Model	Description	Cal-Due Dat
------	-----	-------	-------------	-------------

Relative supporting documentation to traceability is on file and is available upon request.

Without consent, this certificate shall not be reproduced except in full, without prior written approval from Tology. All results of this calibration relate only to the items that were calibrated.

In the event this certificate contains the calibration results of a subcontractor, those results will be clearly identified within this certification.

  
Certifying Authority


**CERTIFICATE OF CONFORMANCE**

A verification has been performed on the instrument below.  
This instrument meets the manufacturer's published  
performance specifications.

Manufacturer / Model Number	: ARA TP-5
Asset Number	: 67212
Serial Number	: NSN
Verification Date	: Nov 20, 1996
Procedure used	: MANUFACTURER'S PROCEDURE
Temperature	: 70F
Humidity	: 50%
Certificate Number	: 951018522
Customer Name	: NAVAL RESEARCH
Agreement Number	: 196418
Technician number	: 93

PO#N00173-97P0527

I further certify that the supplies or services are of  
the quality specified and conform in all respects with  
the contract requirement, including preservation,  
packaging, and physical item identification (part number),  
and are in the quantity shown on the accompanying TELOGY  
agreement referenced above.

  
Certifying Authority  
Telogy Incorporated


**CERTIFICATE OF CONFORMANCE**

A verification has been performed on the instrument below.  
This instrument meets the manufacturer's published  
performance specifications.

Manufacturer / Model Number	: ARA TP-5
Asset Number	: 66952
Serial Number	: NSN
Verification Date	: Nov 20, 1996
Procedure used	: MANUFACTURER'S PROCEDURE
Temperature	: 70F
Humidity	: 50%
Certificate Number	: 951018521
Customer Name	: NAVAL RESEARCH
Agreement Number	: 196418
Technician number	: 93

PO#N00173-97P0527

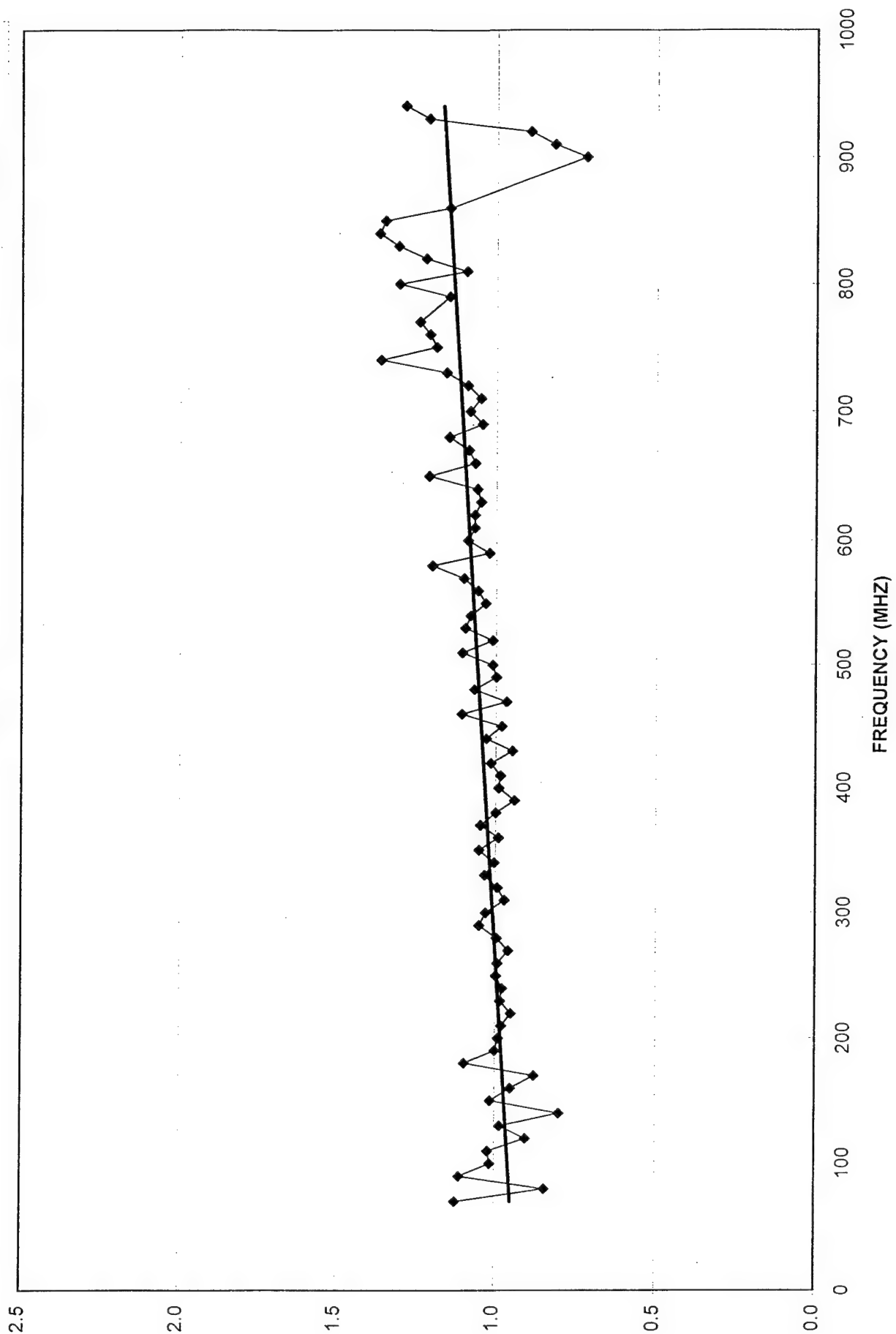
I further certify that the supplies or services are of  
the quality specified and conform in all respects with  
the contract requirement, including preservation,  
packaging, and physical item identification (part number),  
and are in the quantity shown on the accompanying TELOGY  
agreement referenced above.

  
\_\_\_\_\_  
Certifying Authority  
Tology Incorporated

**APPENDIX D**  
**FULL SIZE CHARTS**

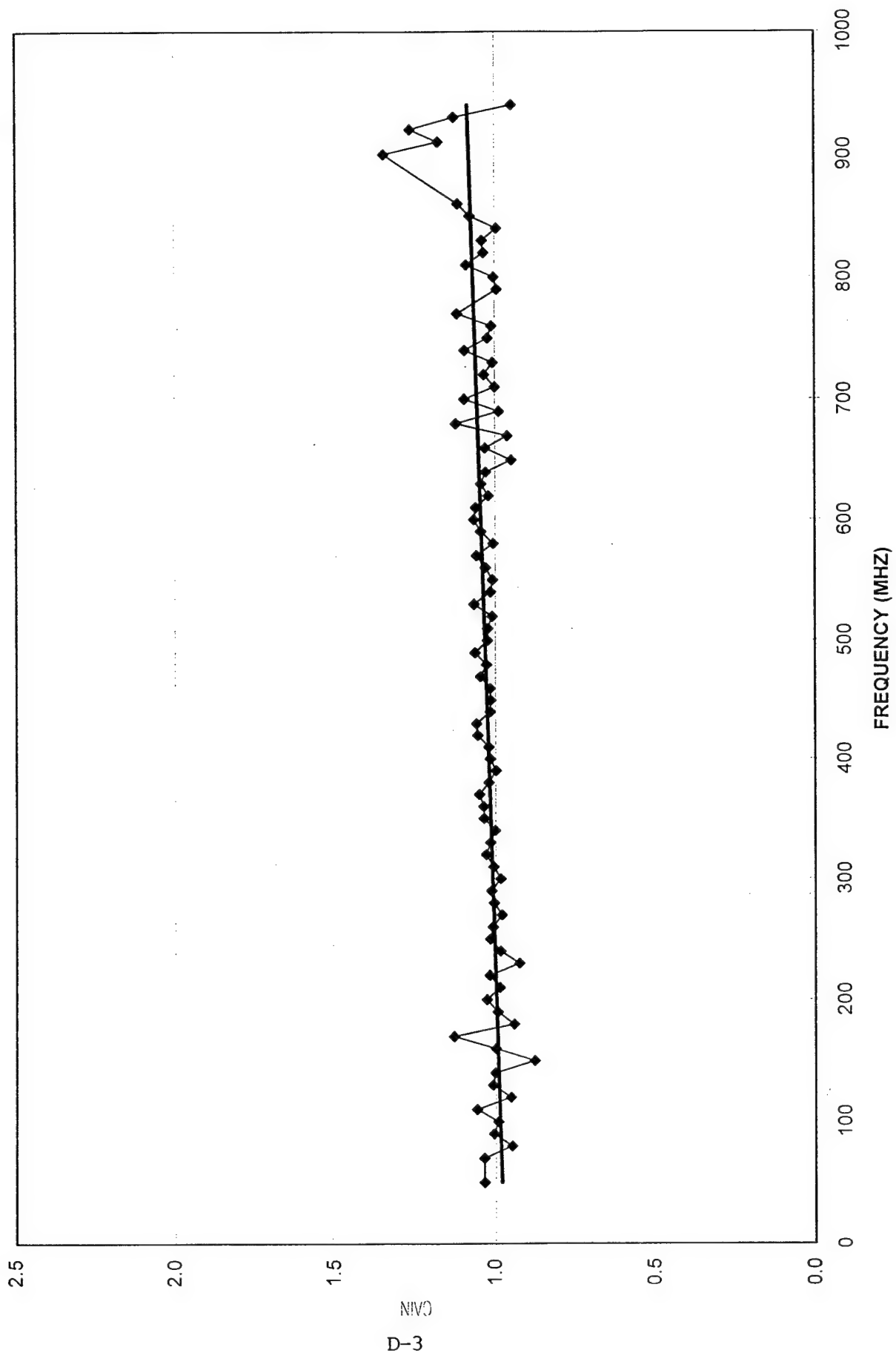
TEST 1  
HORZ @ 90  
HORZ XMIT

---(CH2)/(CH2 BASE)  
---TREND



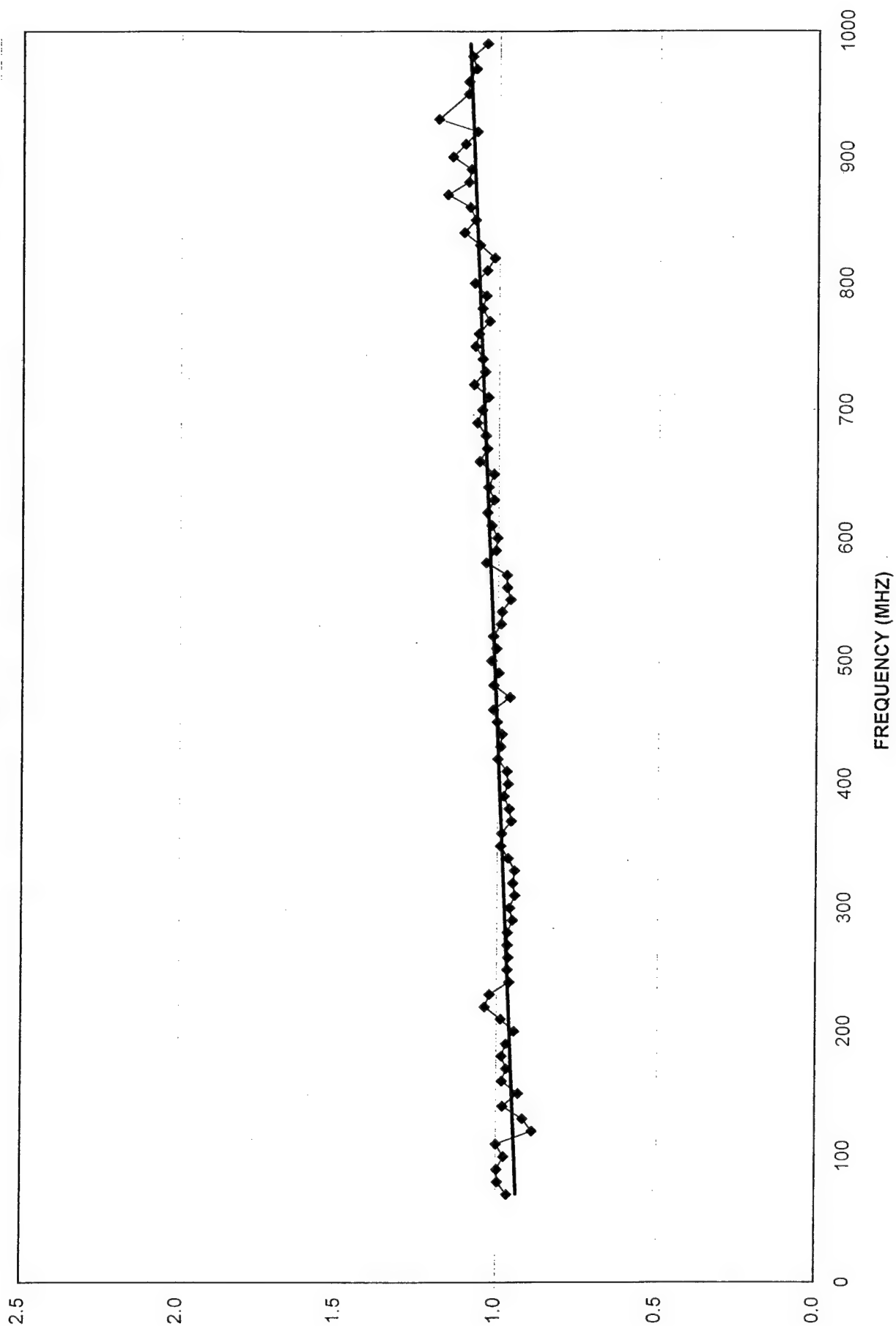
TEST 1  
HORZ @ 180  
HORZ XMIT

◆ (CH1)/(CH1 BASE)  
— TREND



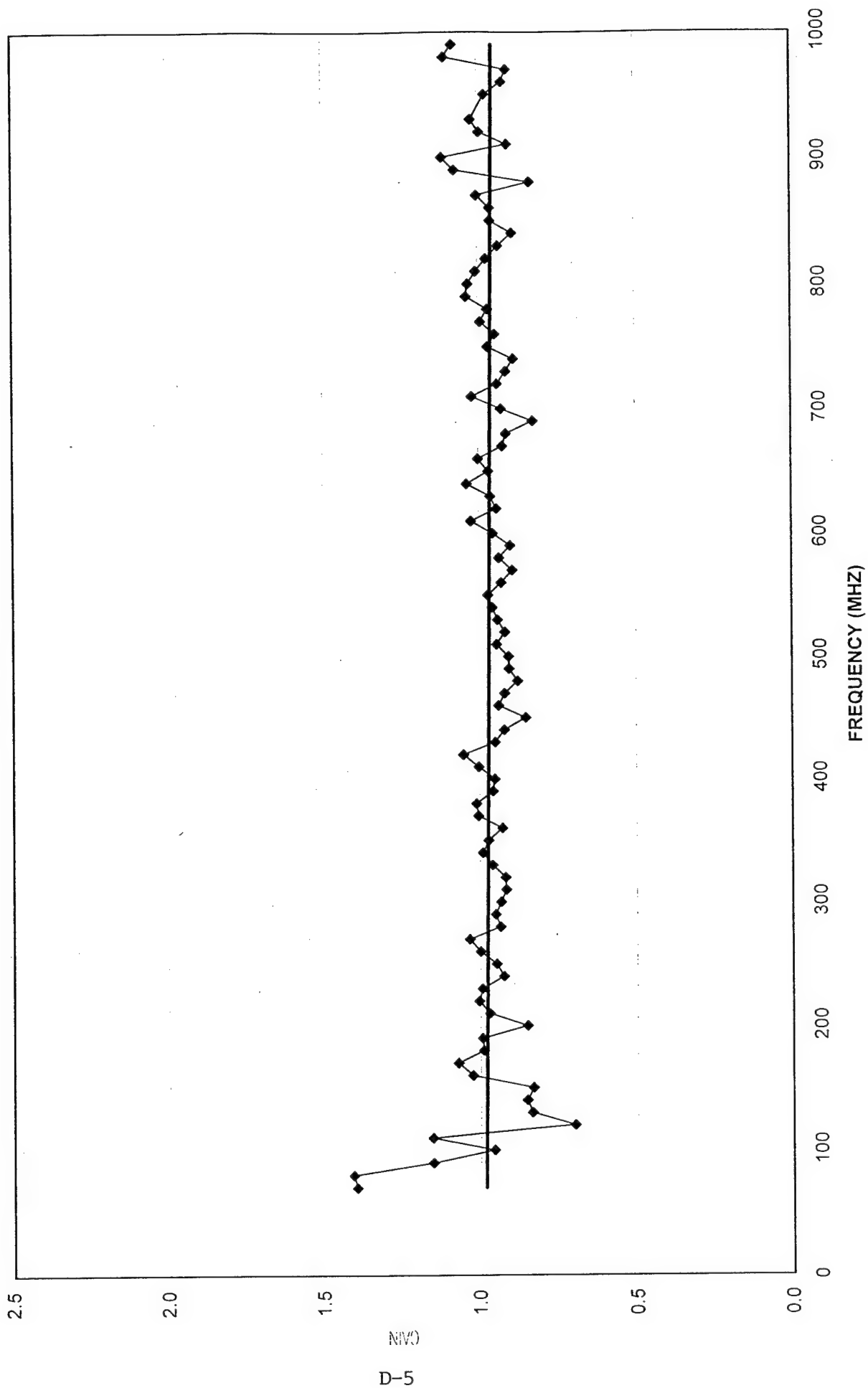
TEST 2  
HORZ @ 180  
XMIT HORZ

—◆— (CH2)/(CH2 BASE)  
— TREND



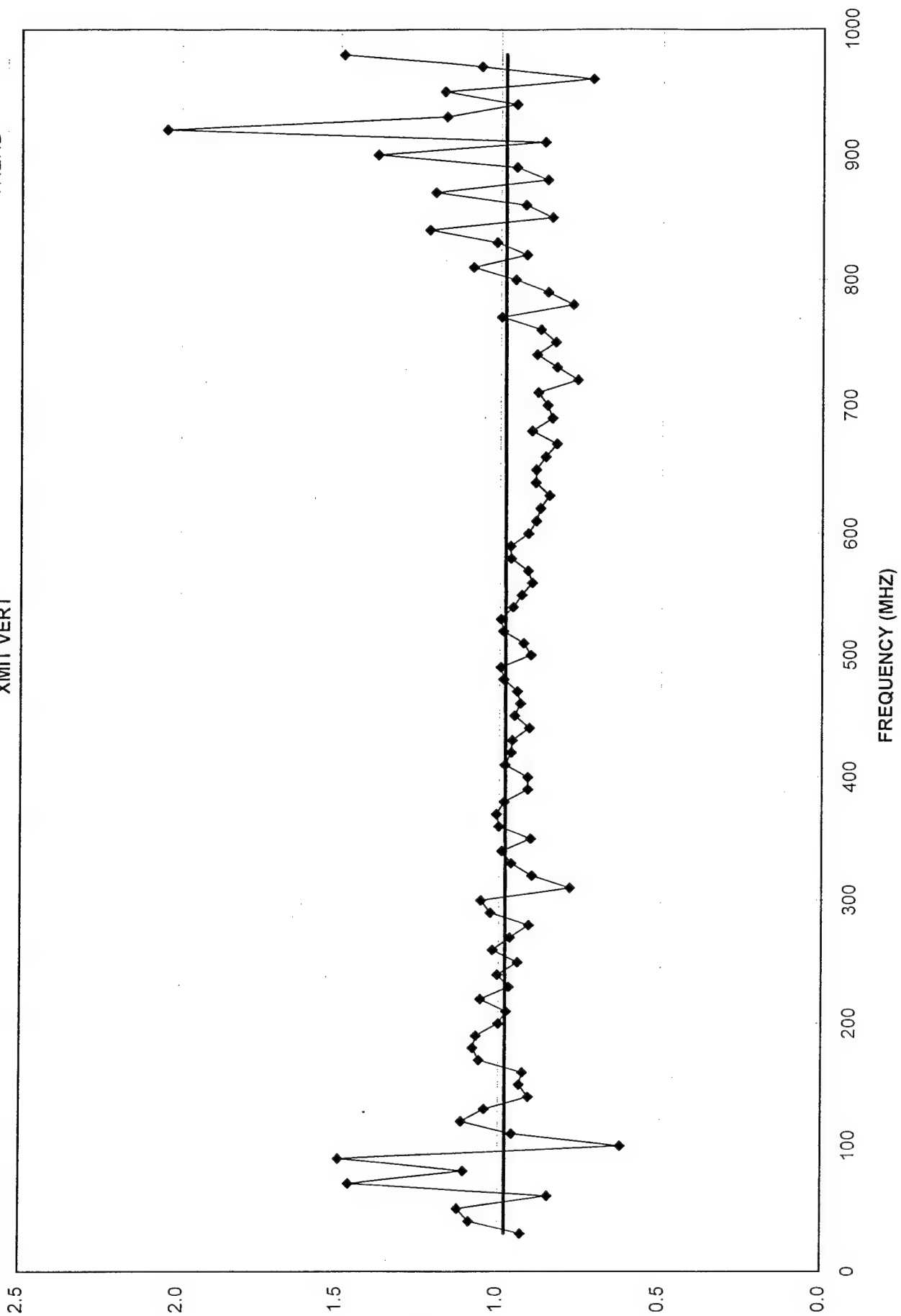
TEST 2  
HORZ @ 90  
XMIT HORZ

—◆— (CH1)/(CH1 BASE)  
— TREND



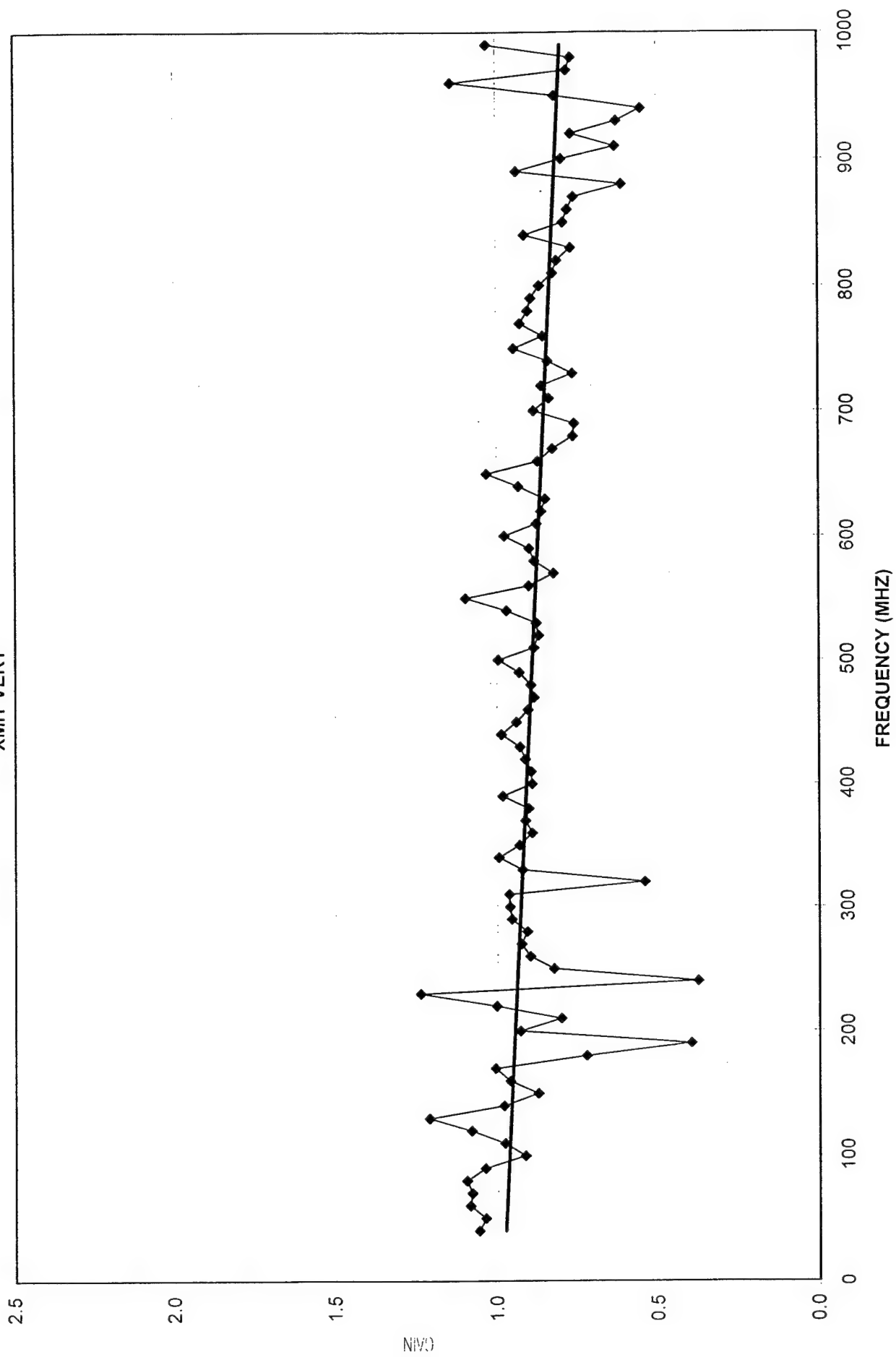
TEST 3  
VERT @ 180  
XMIT VERT

—◆— (CH2)/(CH2 BASE)  
— TREND



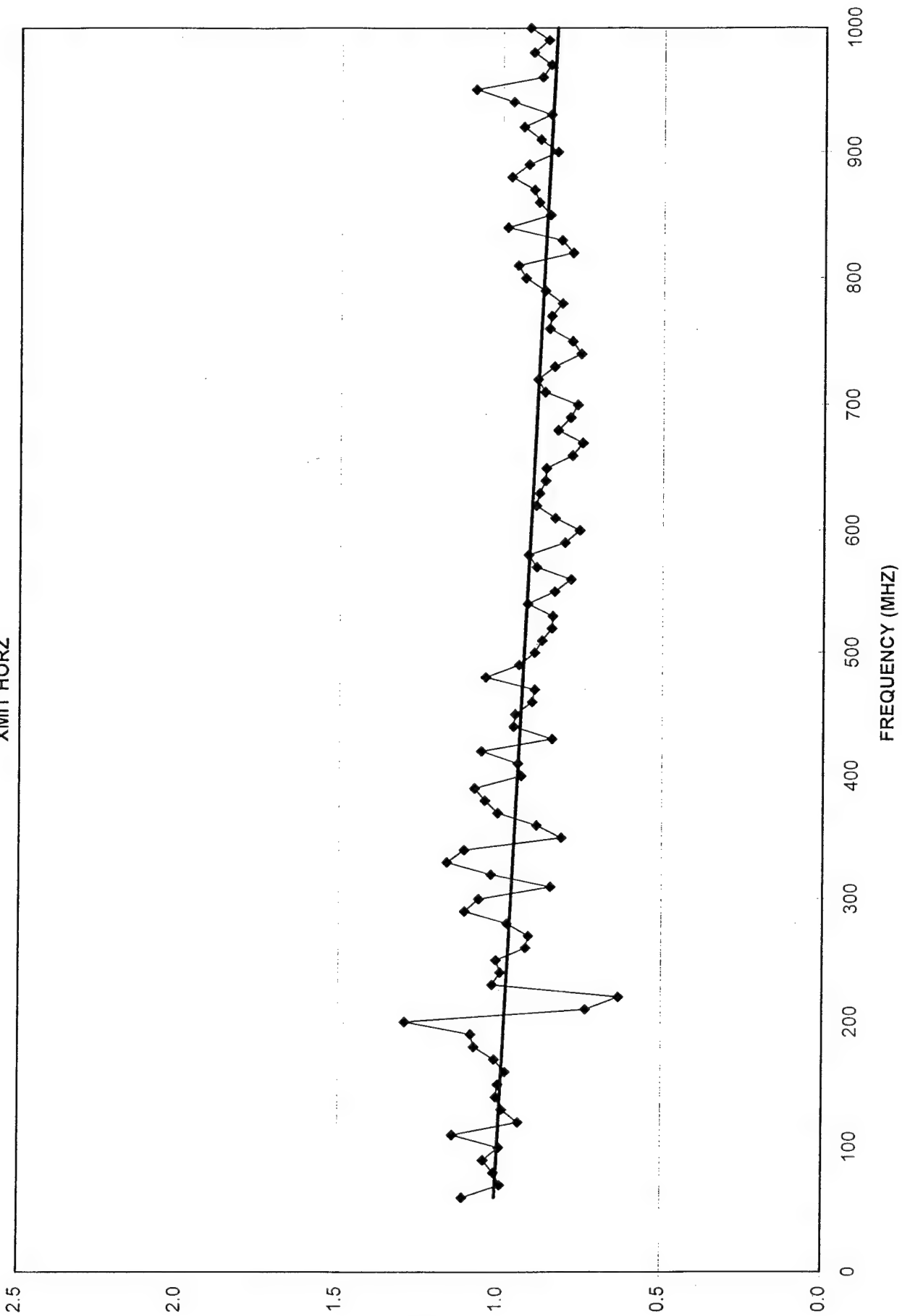
TEST 3  
VERT @ 90  
XMIT VERT

—◆— (CH1)/(CH1 BASE)  
— TREND



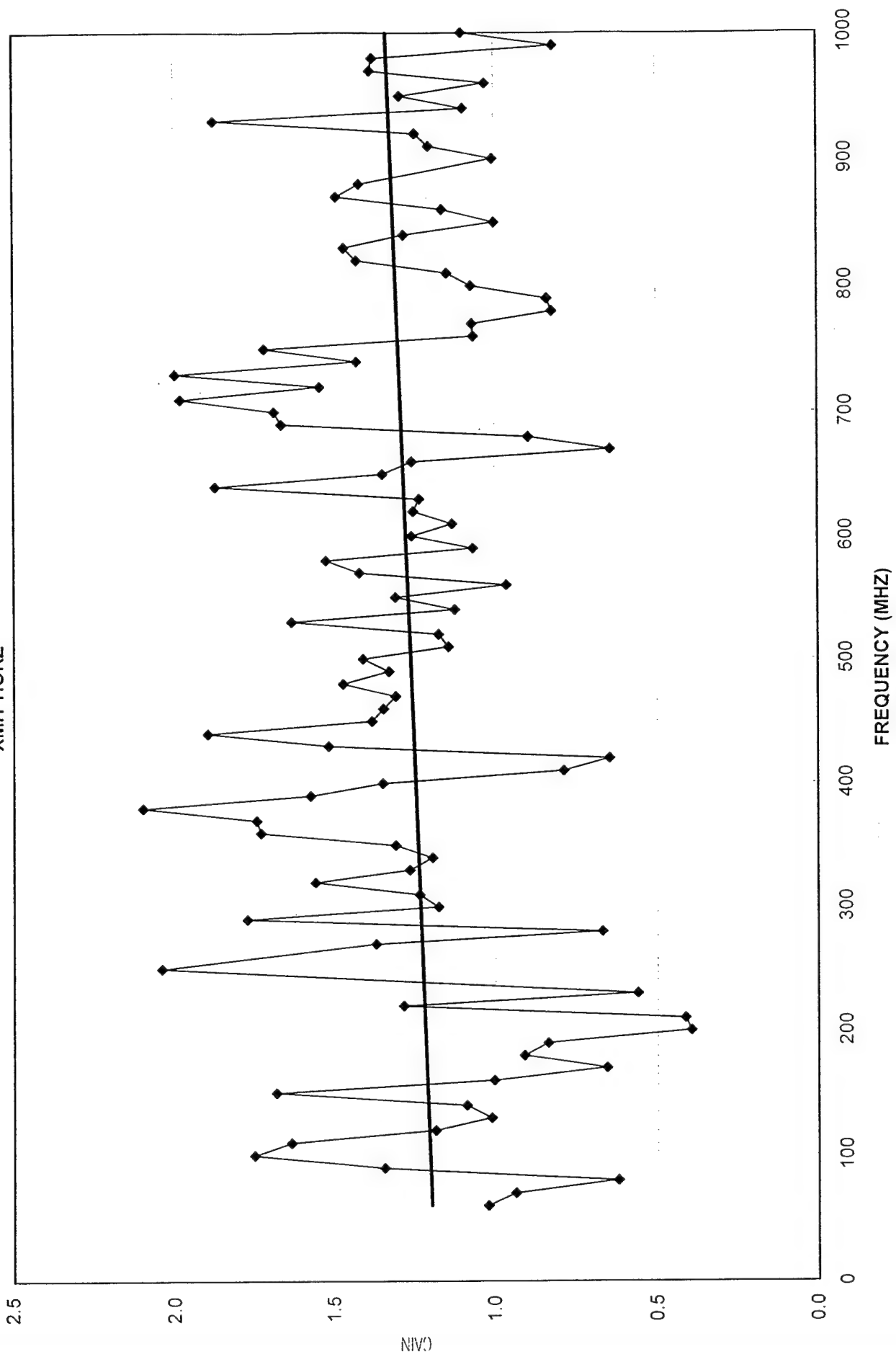
TEST 4  
HORZ @ 180  
XMIT HORZ

—◆— (CH2)/(CH2 BASE)  
— TREND



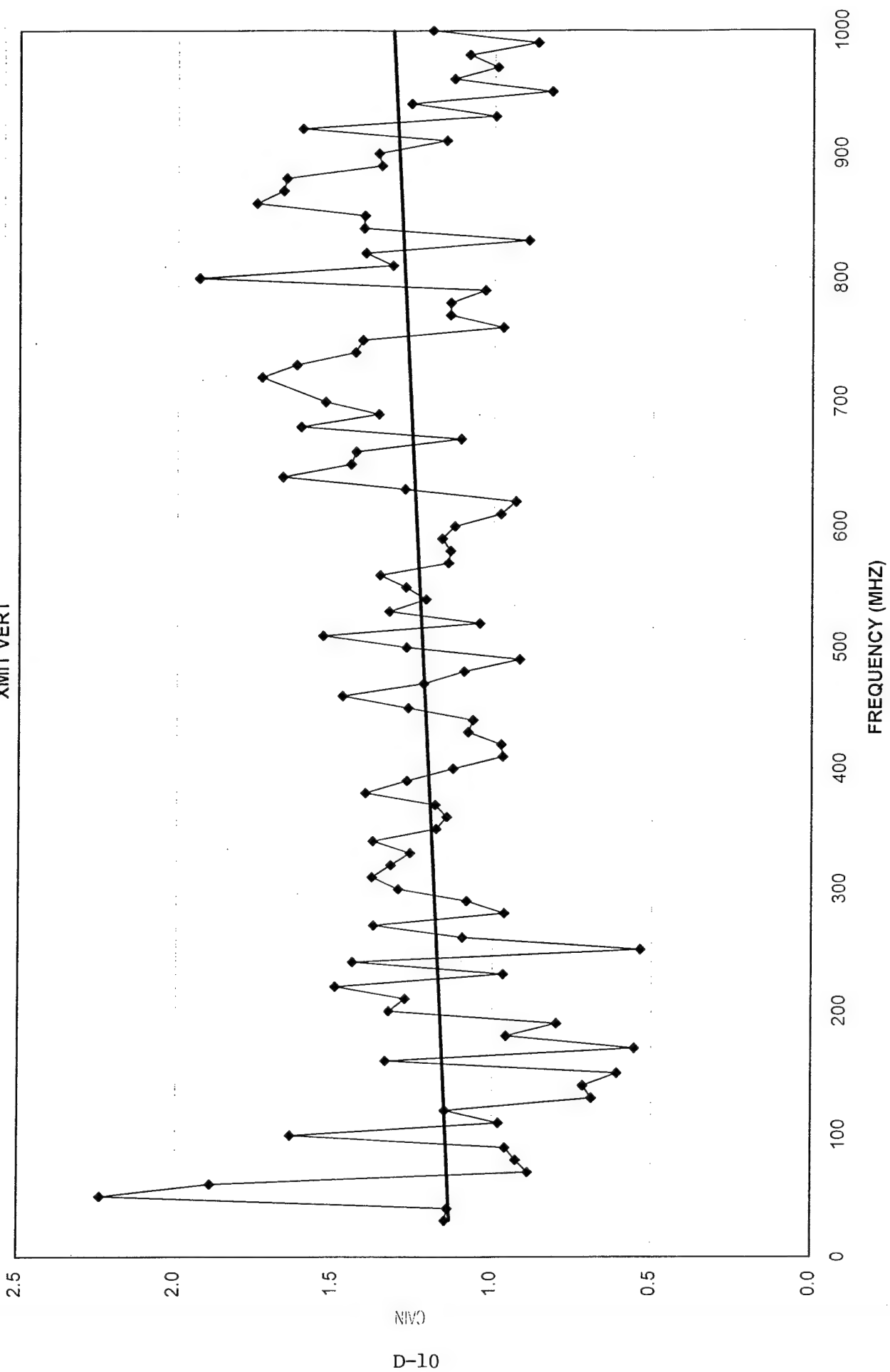
TEST 4  
VERT @ 180  
XMIT HORZ

—◆— (CH1)/(CH1 BASE)  
— TREND



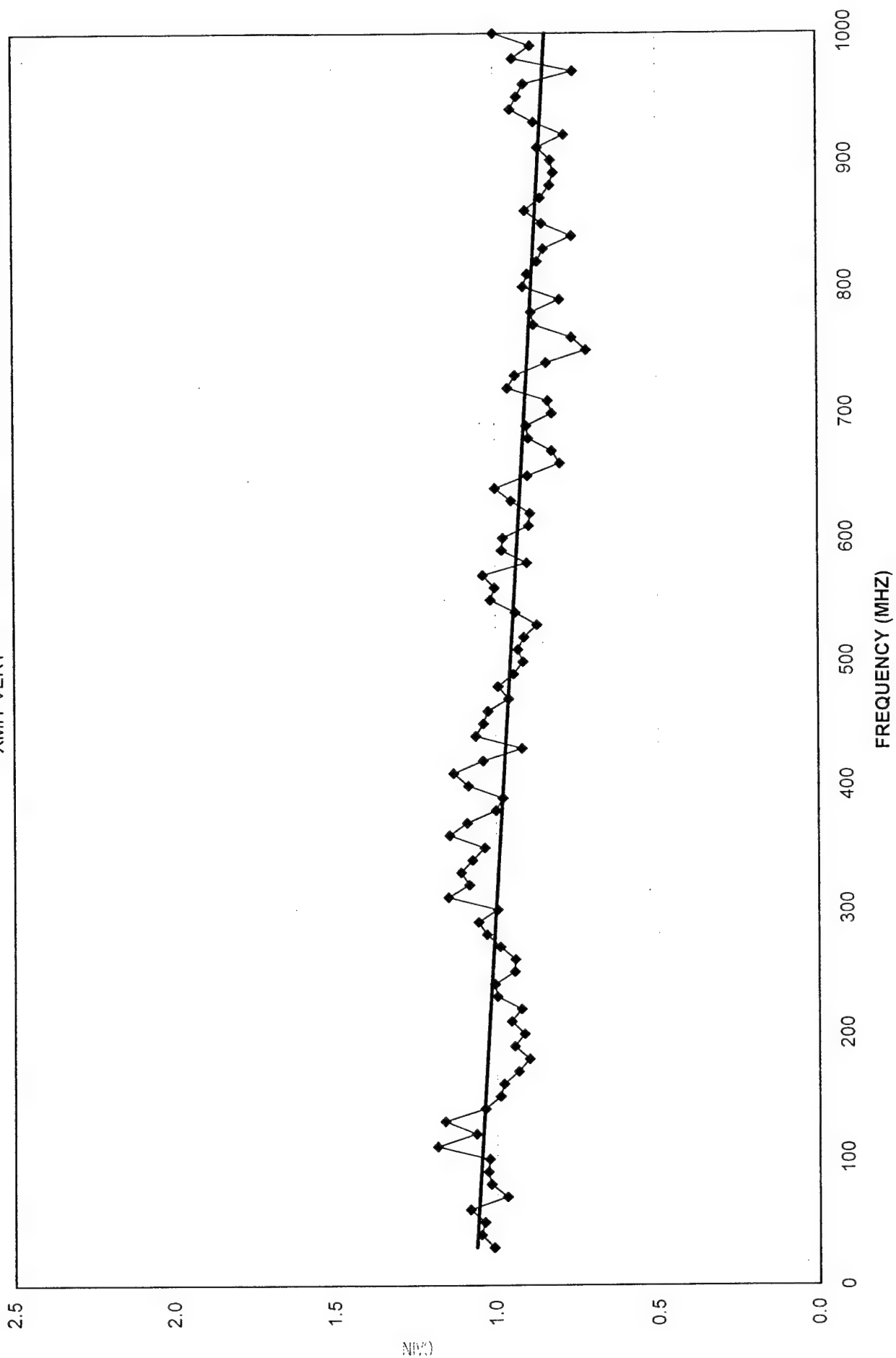
TEST 5  
HORZ @ 180  
XMIT VERT

—◆— (CH1)/(CH1 BASE)  
— TREND



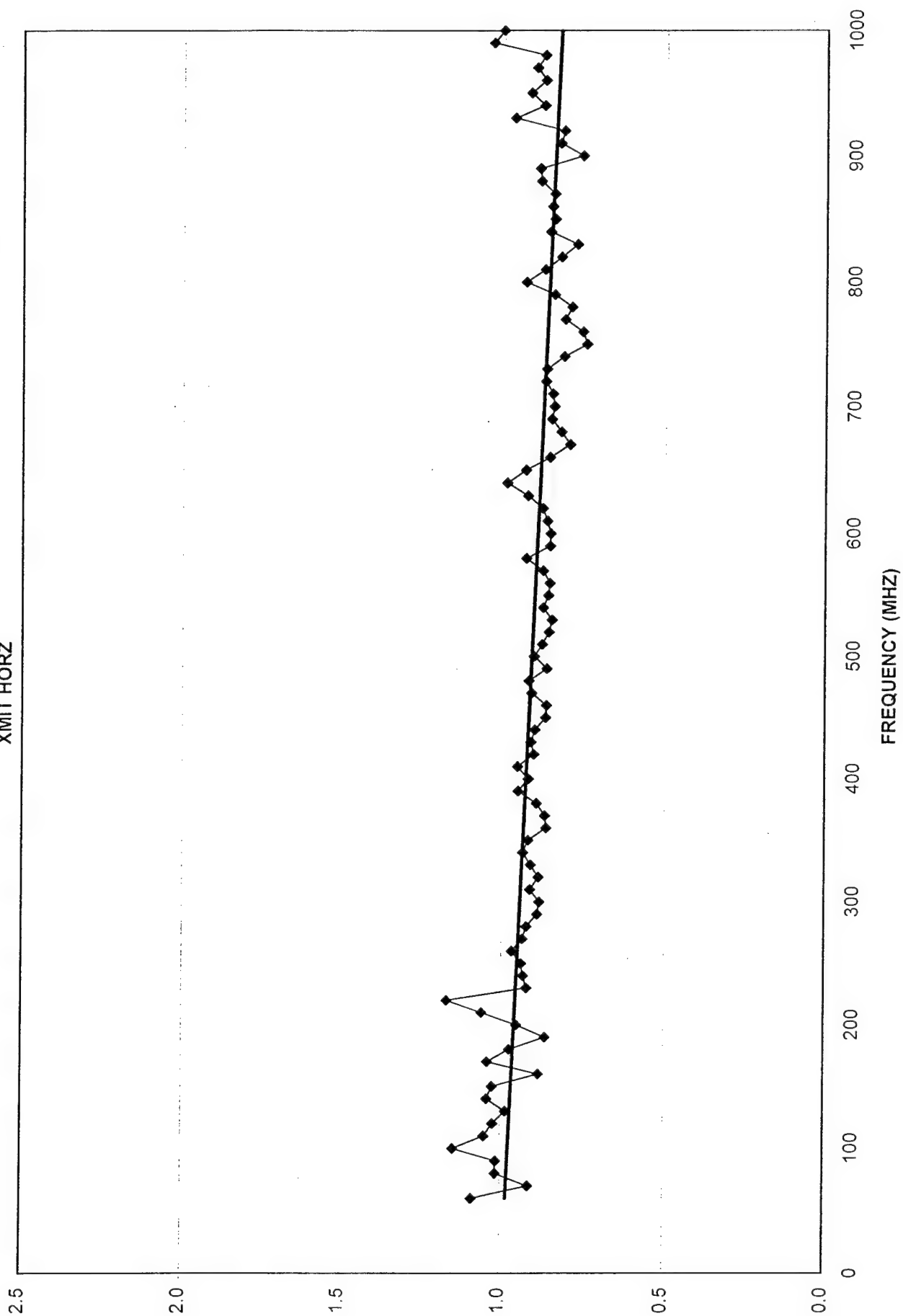
TEST 5  
VERT @ 180  
XMIT VERT

—◆— (CH2)/(CH2 BASE)  
— TREND



TEST 6  
HORZ @ 180  
XMIT HORZ

—◆— (CH2)/(CH2 BASE)  
— TREND

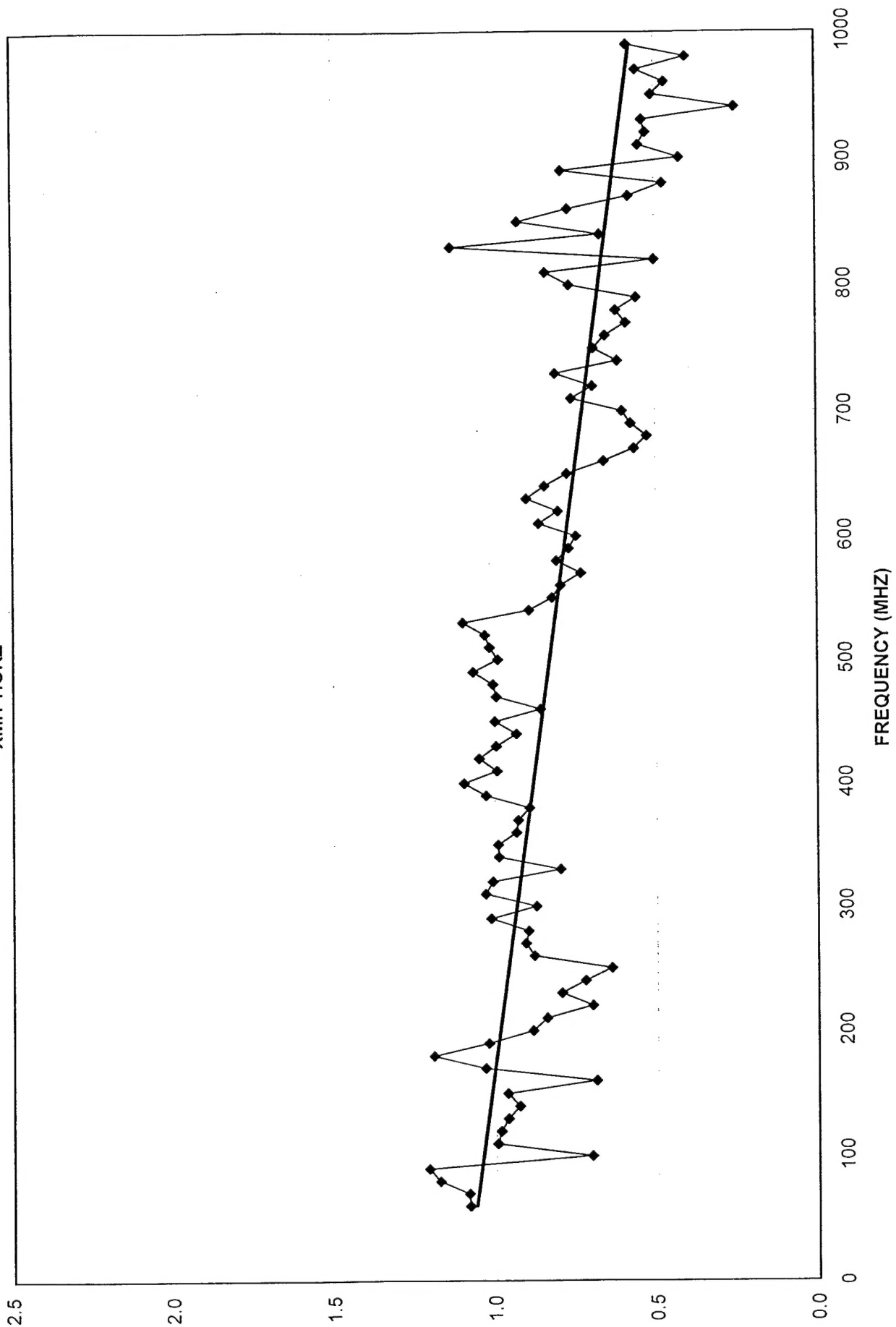


NEC

D-12

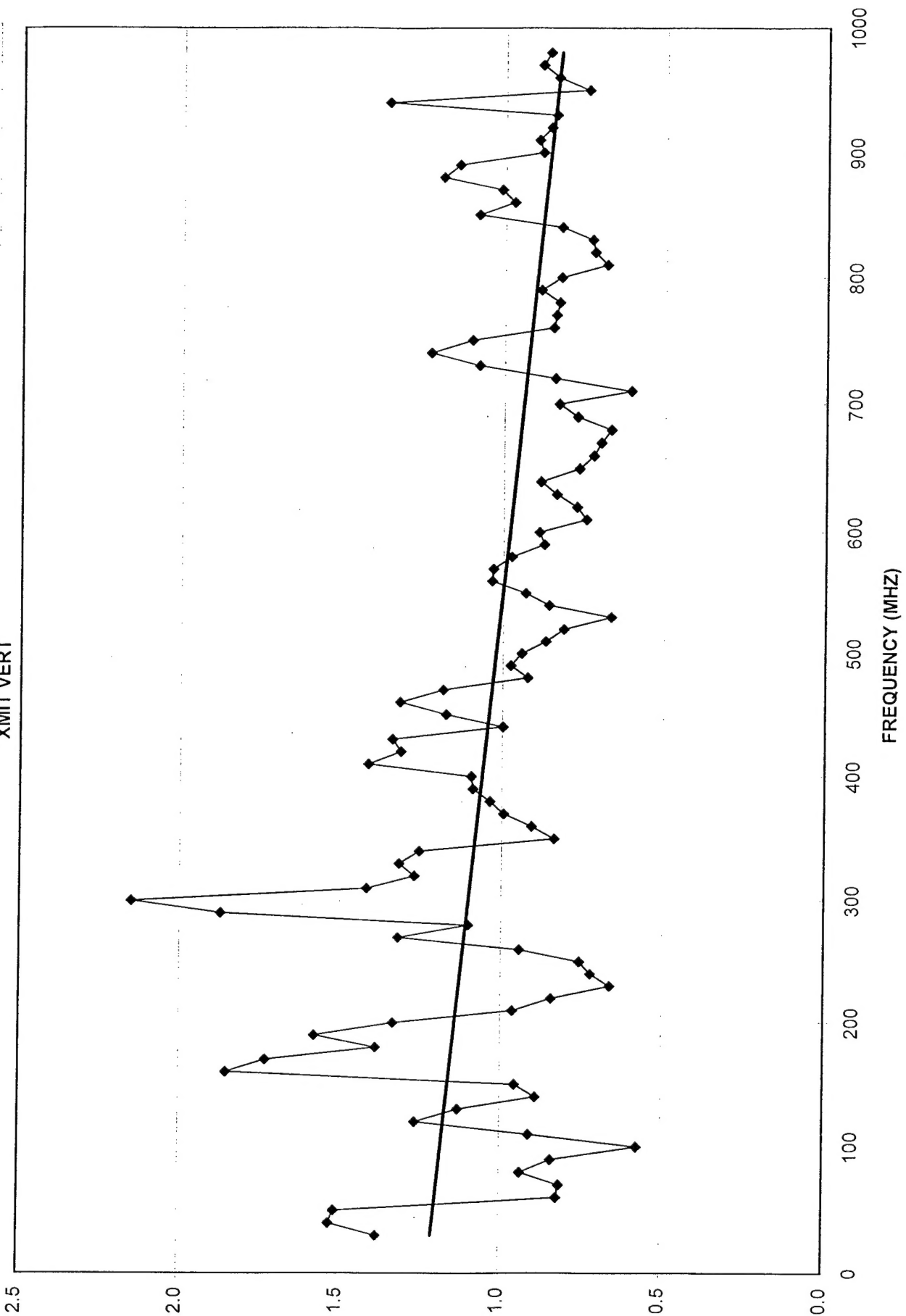
TEST 6  
HORZ SHIELD @ 90  
XMIT HORZ

—◆— (CH1)/(CH1 BASE)  
— TREND



TEST 7  
VERT @ 180  
XMIT VERT

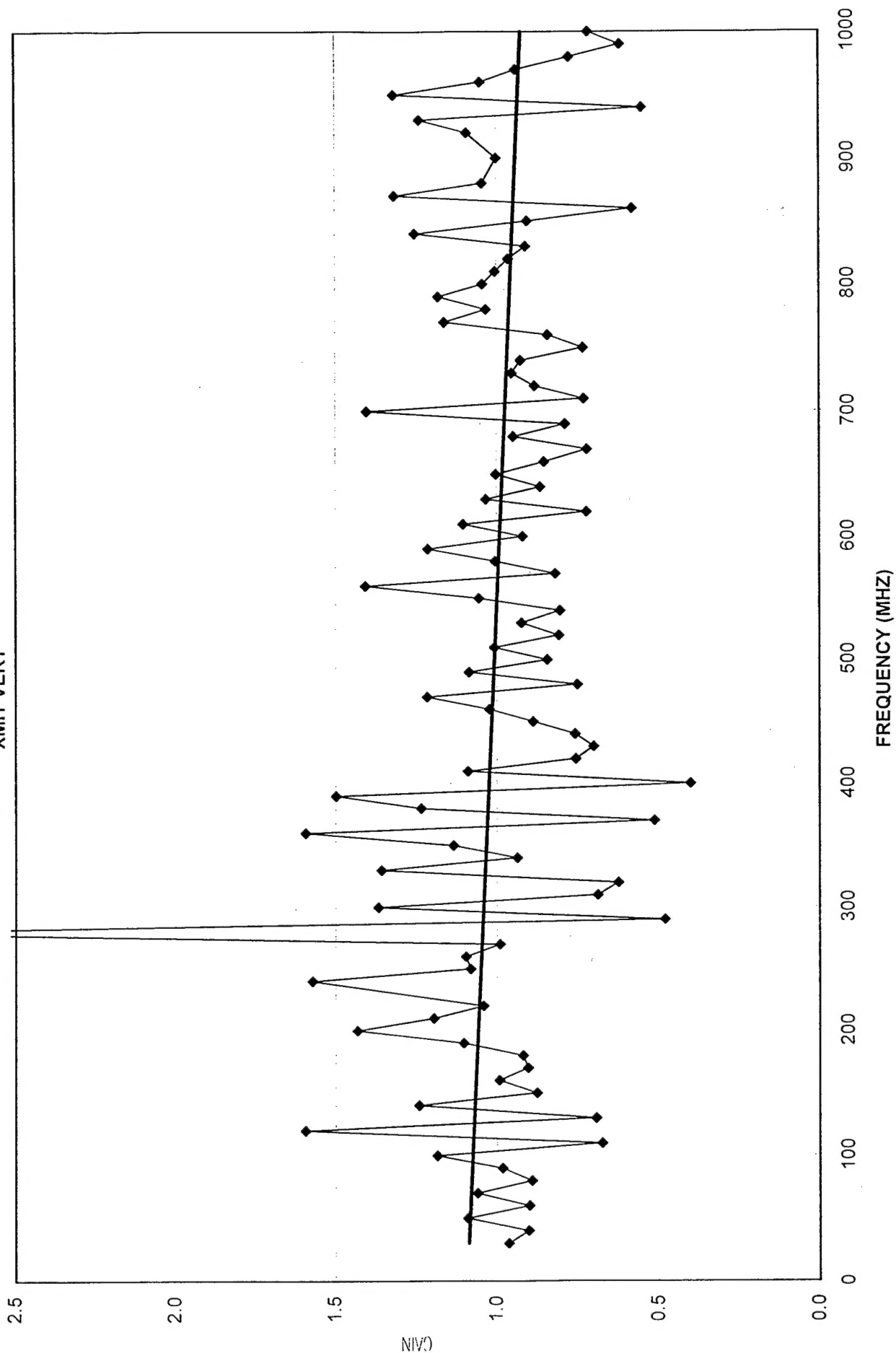
—◆— (CH2)/(CH2 BASE)  
— TREND



NWC

—◆— (CH1)/(CH1 BASE)  
 ——— TREND

TEST 8  
 VERT SHIELD @ 90  
 XMIT VERT



(N/A)

TEST 8  
VERT @ 180  
XMIT VERT

—◆— (CH2)/(CH2 BASE)  
— TREND

